

THE CHEMICAL ELEMENTS

BY THE SAME AUTHOR .
ATOMIC THEORIES

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THE CHEMICAL ELEMENTS

BY

F. H. LORING

AUTHOR OF "ATOMIC THEORIES"

WITH 14 TABLES AND 4 DIAGRAMS

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PREFACE

THE aim of this book is to present in a simple and concise form certain characteristics of the chemical elements as studied from the point of view of their quantitative grouping and their structural binding—using the latter term in a wide sense—and to bring into prominence the significance of “space physics” as applied to certain phenomena involved.

It is suggested in this connexion that the reader does not want old ideas re-hashed, but the newer ideas made clear. With this object in view the writer has presented a definite line of study based almost entirely on recent work, and, together with a few developments of his own, has endeavoured to make the subject as clear as straightforward argument will permit.

Attention may be drawn to the practice herein adopted of summarizing each chapter, except Chapters I and XIV; and in a few instances additional remarks have been incorporated in the summaries.

Chapters II, III, IV, and V are based upon several of the writer's contributions to the *Chemical News*; and, it is to be noted that Chapter II, as originally written in 1912, is reproduced with a view to giving some early ideas in connexion with the missing elements in the periodic table, thus making it a sort of historical introduction to the chapters immediately following.

vi THE CHEMICAL ELEMENTS

By the kind permission of Messrs. H. O. Lloyd & Co., Ltd. (of London), the writer is able to reproduce in Chapter I a considerable portion of his pamphlet entitled "Definition of Isotopes," belonging to his "Science by Definition Series"—but new matter has been added.

F. H. L.

LONDON

September, 1923

CONTENTS

CHAPTER I

	PAGE
THE ELEMENTS: THEIR ATOMIC NUMBERS: SYMBOLS: ATOMIC WEIGHTS: AND ISOTOPES	I

CHAPTER II

CERTAIN NUMERICAL RELATIONS IN THE PERIODIC CLASSIFICATION OF THE ELEMENTS, AND A FEW OBSERVATIONS CONCERNING THEIR CHARACTER	19
---	----

CHAPTER III

THE MISSING ELEMENTS IN THE PERIODIC TABLE	25
--	----

CHAPTER IV

THE RELATIVE DISTRIBUTION OF THE ELEMENTS IN THE EARTH'S CRUST AND ITS BEARING ON THE PROBLEM OF MISSING ELEMENTS, TOGETHER WITH A NEWER TYPE OF PERIODIC TABLE	31
---	----

CHAPTER V

THE PRESENCE OF SCANDIUM IN THE SUN, AND MODERN VIEWS CONCERNING THE PROBLEM OF ELEMENT EVOLUTION IN CONNEXION WITH THE FOREGOING STUDIES	37
---	----

CHAPTER VI

"PLACE PRINCIPLE" AS A GENERAL FACTOR IN THE PERIODIC CLASSIFICATION AS WELL AS IN THE BOHR ATOM INVOLVING QUANTUM RELATIONS	46
--	----

CHAPTER VII

HOW THE "BINDING" OF ELECTRONS IN SPECTRAL ANALYSIS LEADS TO, OR IS CONNECTED WITH, OTHER COGNATE IDEAS	56
---	----

CHAPTER VIII

CHEMICAL PHENOMENA AS A BINDING PROCESS WHICH IS ILLUSTRATED BY EXAMPLES SHOWING GEOMETRICAL STRUCTURE	67
--	----

viii THE CHEMICAL ELEMENTS

CHAPTER IX

	PAGE
GEOMETRY OF SPACE A FACTOR IN PHYSICS	75

CHAPTER X

RADIATION AND ENERGY: PLANCK'S LAW OF RADIATION	82
---	----

CHAPTER XI

THE FUNDAMENTAL ASPECTS OF ENERGY FROM THE STAND- POINT OF ATOMIC PHYSICS	87
--	----

CHAPTER XII

THE ELECTRICAL NATURE OF THE ATOM AS REVEALED BY RADIO-ACTIVITY, AND THE CLASSIFICATION OF THE RADIO-ISOTOPES	95
---	----

CHAPTER XIII

MAGNITUDES AND RELATIONSHIPS	113
--	-----

CHAPTER XIV

LIMITATIONS IN THEORY	123
---------------------------------	-----

APPENDIX I

THE PROBLEM OF THE SYNTHETIC PRODUCTION OR TRANS- FORMATION OF ELEMENTS ON A COMMERCIAL SCALE, AND SOME IDEAS ARISING THEREFROM	131
---	-----

APPENDIX II

SPECIFICATION OF AN ELEMENT	144
---------------------------------------	-----

APPENDIX III

ISOTOPES: RECENT ADVANCES MADE BY DR. F. W. ASTON	147
---	-----

APPENDIX IV

IS THERE AN ELEMENT OF ZERO ATOMIC NUMBER?	154
--	-----

APPENDIX V

BRIDGING THE GAP IN THE SPECTRUM	163
NAME INDEX	167
SUBJECT INDEX	169

"This suggests striving for an ideal—to show, not that the laws of nature come from a special construction of the ultimate basis of everything, but that the same laws of nature would prevail for the widest possible variety of structure of that basis."—A. S. EDDINGTON—*Mathematical Theory of Relativity*.

THE CHEMICAL ELEMENTS

CHAPTER I

THE ELEMENTS: THEIR ATOMIC NUMBERS, SYMBOLS, ATOMIC WEIGHTS, AND ISOTOPES

INASMUCH as the studies recorded in these pages are largely based upon the classification of the chemical elements, it is desirable to give here a list of these in the order of their atomic numbers, so that the reader may have before him an up-to-date table of the values used in the developments to follow. To make the accompanying table (I) complete, the isotopes, thus far discovered, are introduced. The atomic weights, it will be seen, are in many cases mean values. For example, boron has two isotopes which are in the quantitative proportion of 27 to 8, so that

$$(11 \times 27 + 10 \times 8)/(27 + 8) = 10.77.*$$

The newer subjects of *isotopes* and *atomic numbers* call for a brief description, by way of definition,

* The isotopic mean value found by Aston is	10.75 \pm 0.07
Recent chemical determinations by Baxter and Scott and by Hönigschmid and Bircken- bach	10.83
Mean value	10.79

Another determination by A. Stock and E. Kuss (*Berichte*, 1923, p. 314) gives the average value 10.80. Using this value in place of 10.83 gives a mean of 10.77.

2. . . THE CHEMICAL ELEMENTS

which is given here. The periodic table below (II) will be made use of in subsequent chapters.

TABLE I

At. No.	Name.	Symbol.	At. Wt.	Isotopes and single values thus far revealed by the positive-ray method.
1	Hydrogen .	H	1.008	1.008
2	Helium .	He	4.00	4
3	Lithium .	Li	6.94	6; 7
4	Beryllium *	Be	9.02	9
5	Boron .	B	10.82	10; 11
6	Carbon .	C	12.005	12
7	Nitrogen .	N	14.008	14
8	Oxygen .	O	16.000	16
9	Fluorine .	F	19.0	19
10	Neon .	Ne	20.2	20; 22
11	Sodium .	Na	23.00	23
12	Magnesium .	Mg	24.32	24; 25; 26
13	Aluminium .	Al	27.0	27
14	Silicon .	Si	28.1	28; 29; (30)
15	Phosphorus .	P	31.04	31
16	Sulphur .	S	32.06	32
17	Chlorine .	Cl	35.46	35; 37
18	Argon .	Ar	39.9	36; 40
19	Potassium .	K	39.10	39; 41
20	Calcium .	Ca	40.07	40; (44)
21	Scandium .	Sc	45.1	45
22	Titanium .	Ti	47.9	48; (50)
23	Vanadium .	V	51.0	51
24	Chromium .	Cr	52.0	52
25	Manganese .	Mn	54.93	55
26	Iron .	Fe	55.84	(54); 56
27	Cobalt .	Co	58.97	59
28	Nickel .	Ni	58.68	58; 60
29	Copper .	Cu	63.57	63; 65
30	Zinc .	Zn	65.37	64; 66; 68; 70
31	Gallium .	Ga	69.71	69; 71
32	Germanium .	Ge	72.5	70; 72; 74
33	Arsenic .	As	74.96	75
34	Selenium .	Se	79.2	74; 76; 77; 78; 80; 82
35	Bromine .	Br	79.92	79; 81
36	Krypton .	Kr	82.92	78; 80; 82; 83; 84; 86
37	Rubidium .	Rb	85.45	85; 87
38	Strontium .	Sr	87.63	88
39	Yttrium .	Yt	89.03	89
40	Zirconium .	Zr	90.6	(90)
41	Niobium †	Nb	93.1	

* Or Glucinium Gl.

† Or Columbium Cb.

ELEMENTS

3

TABLE I—(continued)

At. No.	Name.	Symbol.	At. Wt.	Isotopes and single values thus far revealed by the positive-ray method.
42	Molybdenum .	Mo	96.0	
43	—	—	—	
44	Ruthenium .	Ru	101.7	
45	Rhodium .	Rh	102.9	
46	Palladium .	Pd	106.7	
47	Silver .	Ag	107.88	107; 109
48	Cadmium .	Cd	112.41	
49	Indium .	In	114.8	
50	Tin .	Sn	118.7	[116; 117; 118; 119; 120; (121); 122; 124]
51	Antimony .	Sb	121.8	121; 123
52	Tellurium .	Te	127.5	
53	Iodine .	I	126.92	127
54	Xenon .	Xe	130.2	(124); (126); 128; 129; 130; 131; 132; 134; 136
55	Cesium .	Cs	132.81	133
56	Barium .	Ba	137.37	
57	Lanthanum .	La	138.9	
58	Cerium .	Ce	140.25	
59	Praseodymium	Pr	140.9	
60	Neodymium .	Nd	144.3	
61	—	—	—	
62	Samarium .	Sa	150.4	
63	Europium .	Eu	152.0	
64	Gadolinium .	Gd	157.3	
65	Terbium .	Tb	159.2	
66	Dysprosium .	Dy	162.5	
67	Holmium .	Ho	163.5	
68	Erbium .	Er	167.7	
69	Thulium .	Tm	169.9	
70	Ytterbium *	Yb	173.5	
71	Lutecium .	Lu	175.0	
72	Celtium .	Ct	—	See p. 23
73	Tantalum .	Ta	181.5	
74	Tungsten .	W	184.0	
75	—	—	—	
76	Osmium .	Os	190.9	
77	Iridium .	Ir	193.1	
78	Platinum .	Pt	195.2	
79	Gold .	Au	197.2	
80	Mercury .	Hg	200.6	(197-200); 202; 204
81	Thallium .	Tl	204.0	
82	Lead .	Pb	207.19	

* Or Neoytterbium Ny.

4 THE CHEMICAL ELEMENTS

TABLE I—(continued)

At. No.	Name.	Symbol.	At. Wt.	Isotopes and single values thus far revealed by the positive-ray method (exclusive of emanations).
83	Bismuth	Bi	209.0	220 = ThEm 218 ? = AcEm
84	Polonium	Po	—	
85	—	—	—	
86	Emanations	RaEm *	222	
87	—	—	—	
88	Radium	Ra	226	
89	Actinium	Ac	—	
90	Thorium	Th	232.2	
91	Uranium X ₂	UX ₂	—	
92	Uranium	U	238.2	

* Or Niton Nt; or Radon Rn. See Table VII; p. 96. See Footnote on p. 10.

EXPLANATION OF TABLE.—Figures in round () brackets are provisional. Figures in square [] brackets are not quite whole numbers. Values in heavy-face type represent, in the case of isotopes, the member in greatest abundance. Heavy-face type is also used for the *single* values.

Most of the above isotopes have been experimentally discovered by F. W. Aston. Sir J. J. Thomson discovered *two* (Ne 20; Ne 22), and A. J. Dempster, by a positive-ray method of his own devising, has discovered a small number. G. P. Thomson determined the single mass value for beryllium and contributed in respect of the values for lithium.

Some of the recent atomic-weight determinations, differing slightly from those above, are as follows:—

Gallium,	69.71	Subject to acceptance by the International Committee on Atomic Weights.
Selenium,	79.37	
Bromine,	79.93	
Antimony,	121.44	
Thallium,	204.4	

The word *isotope*, suggested by Soddy, from *ἴσος* (equal) and *τοπος* (a place), is applied to atoms, meaning that isotopes are atoms chemically and electrochemically alike, though they may differ in atomic weight or atomic mass.

Referring to the periodic classification of the elements, it will be apparent that recurrence of type is a characteristic of the elements, so that, taking an example, lithium, sodium, potassium, rubidium

and caesium fall into Group I, these elements having closely allied chemical and electrochemical properties ; but these recurring types are not absolutely identical, since they can be separated from one another by chemical methods, and their atomic weights differ considerably, their respective values being 6.94, 23.00, 39.10, 85.45, 132.81. Here we have elements whose atoms taken together as a *group* approximate to isotopes ; but it was not until a study was made of the radioactive atoms which are undergoing spontaneous disintegration that the true isotopes were revealed.

It was found that, as these elements disintegrated by throwing off α -particles (helium atoms, each one of which carried two unit positive charges of electricity) and β -particles (negative electrons, each one of which was a unit of negative electricity), the type of atom changed chemically and electrochemically, but the types recurred in consequence, and when such recurring types of atom were mixed together they could not be separated again by chemical methods, though it was found that they had atomic weights differing by several whole-number units. Moreover, the final end-product of change was a non-radioactive atom which had all the characteristics of common lead. There were, in fact, several of these leads corresponding to, or resulting from, the several lines of disintegration, and yet their masses could not be alike. Here then is a process which gives rise to atoms differing in mass or atomic weight, yet chemically so closely allied that they could not be separated once they were mixed together.

This was a new principle in chemistry hardly expected at the time of discovery, though Crookes had at an early date (1886) suggested that what we call atomic weights may not be values representing the actual masses of the atoms of a given element, but that they might turn out to be mean or average figures, and that consequently the individual atoms

6 . . THE CHEMICAL ELEMENTS

varied appreciably in mass. This came as a surprise to many as they had thought that, for example, the element chlorine (taken in bulk quantity) was made up of myriads of atoms whose individual masses were all alike.

This idea was partly supported by very accurate determinations of the atomic weight, this value being 35.46, relative to oxygen taken as an exact whole number 16. Of course it was known that these determinations involved enormous numbers of atoms, but the constancy of this value, 35.46, at least showed that, whatever might be the actual values assigned to the atoms, there was no variation in the mixture.

It was not until Aston improved the positive-ray method of Sir J. J. Thomson that chlorine was found to be a mixture of atoms of masses 35 and 37 in about the respective proportion of 3 to 1, the mean value being 35.46.* This, then, meant that there were two *species* of chlorine atoms, and that they were present in constant proportions. Stating this in another way, it was thought that a cubic centimetre of chlorine had 10²³ atoms *all alike* in mass, the individual mass value relative to oxygen 16 being 35.46. Similarly, a cubic centimetre of oxygen had 10²³ atoms, each one of which had a mass of 16. In the instance of chlorine, this idea turned out to be wrong, though the atomic weight of chlorine was not in question. In the meantime, certain eminent chemists had determined the atomic weight of lead

* If the atomic weight of the element is accurately known, then in the case of two isotopes, for example, of masses 35 and 37, they must be present in such proportions as to give the atomic weight determined by chemical means; and in this case the proportions are about 3 to 1 respectively. This may be figured thus:—

$$\begin{array}{r} 35 \times 3 = 105 \\ 37 \times 1 = 37 \\ \hline 4) \quad 142 \\ \quad 35.5 \end{array}$$

which had accumulated from radio-active change due to the disintegration starting with thorium; and it was compared with another lead which was the end-product of the disintegration of radium, with the result that there was a difference of about two whole-number units between the respective values obtained; and the measurements were of great accuracy.

Then again, when the atomic weight of ordinary lead, not a product of known radio-active change, was carefully re-determined with the same refinement of method, still another value was obtained. Moreover, when these leads were mixed together they could not be separated from each other, as could be done in the case, for example, of the mixture of rubidium and caesium.

There were other similar cases detectable amongst the radio-active products; so that there was an abundance of evidence of atoms really differing in mass yet identical chemically. The periodic law, as ordinarily understood, was then seen to be, without doubt, not rigorously true in that the chemical properties of the elements could not be a function of their atomic mass. This law is known to be a remarkable generalization of great value and significance, yet the absence of exact relations between the atomic weights and the ordering of the elements in the table make it evident that the periodic relations are not accurately dependent upon atomic weight. Atoms of the kind indicated above, that is to say, atoms differing in mass, yet chemically identical, were called isotopes, since they would fall into exactly the same place in the periodic table; hence the appropriateness of the term *isotope*, from *isos*, equal or alike, and *topos*, a place. The *place* is not, however, a *group*-place, but a more restricted compartment into which the individual atoms fall. The periodic table then becomes a pigeon-hole arrangement, in which case each lacuna is a place,

and those atoms falling into the places in transverse alignment form collectively the *group*. This will be clear if the reader will refer to any periodic table, for he has only to remember that some of the places will contain isotopes—in some instances as many as eight. There are, however, pigeon-holes which do not contain isotopes; for example, those containing carbon, nitrogen, oxygen, and fluorine, since the atoms of each of these elements are practically all alike and practically whole numbers, 12, 14, 16, and 19 respectively. It is necessary to use the word *practically* in this definition for we do not know yet whether there will be minute fractions attached to some of these values nor whether such small fractions will be all alike. Should there be a *variation* in this respect there would then be *second-order isotopes*. It may be noted here that hydrogen has a fractional mass (0.008) which is large relatively to the whole-number part, and the mass of the nitrogen atom seems to have a similar fraction, but of course it is relatively smaller.

Thus it will be seen that in classifying the elements by atomic weight or atomic mass it is not a determining factor in itself, though it has been a general guide in arriving at the periodic classification. This is in full accord with radio-active phenomena, which represent other lines of investigation; and it is desirable to strengthen the argument by showing that *radio-activity, isotopes, the periodic classification of the elements, their atomic weights and the electrical properties of the atom*, as revealed by radio-activity, are all in harmonious relationship. To this end, considering again radio-activity, it was found that the chemical and electrical characteristics of the atom underwent a definite change at each step in the process of disintegration; that is to say, taking an example, when radium spontaneously disintegrated by giving off positively charged helium atoms, it lost its radium characteristic and became an inert

gas. This is due to the experimental fact that, considering the radium atom by itself, it belongs to Group II in the periodic classification, and therefore, when it loses a helium atom "carrying away" * with it two positive charges, the electrical state of the atom is thereby altered, or reduced, by the two unit charges which bring it into Group O, to which all the other inert gases belong.

This process of change may be stated in a different way, namely, that it is the change of *atomic number*, † helium being No. 2, which brings about in this case the change of atomic type by two electrical units. In the case of the expulsion of an electron (β -particle), this is *equivalent* ‡ electrically to the restoration of one positive charge, and this positive charge being associated with a mass of unity having an atomic number of 1, this unit has to be added to the atomic number of the atom when losing a negative electron. For instance, radium B has an atomic number of 82. If it loses a negative electron, this is equivalent to the addition of 1, then $82 + 1 = 83$, which is the atomic number of the resultant atom, RaC. 83 is the atomic number of the lacuna containing bismuth (Table I), and RaC is like bismuth. It will be seen that the electron, being a negative unit of electricity when it leaves the atom, causes the loss of this unit charge and so alters the electrical state of the atom by one unit (this is the reverse of the other action, as when a helium atom is expelled carrying two positive charges, this is equivalent to the gain of two units of negative electricity), consequently the atom would then be shifted back † one

* This is not quite a correct expression, as it is not exactly a state of "carrying," since its charge is determined by the relative quantity of positive and negative electricity in the atom.

† The principle of Atomic Number is more fully explained further on by another line of research due to Moseley.

‡ From the point of view of the direction of disintegration (devolution) this change is a *backward* one, but from the point of view of evolution from hydrogen to uranium the general direction is reversed, so that this change then becomes a *forward* one.

10 THE CHEMICAL ELEMENTS

place in the periodic classification, as instanced by RaB of Group IV changing into RaC of Group V. This is sometimes referred to as a β -particle change, or more generally a β -ray change. It will be seen that the charged particles emitted in radio-active change give rise to a definite alteration in the chemical properties of the resultant atom ; but in the case of RaB it has only lost a mass due to that of the electron, which is about 1/1840th part of the mass of the hydrogen atom of atomic weight 1.008. This change does not, therefore, produce an appreciable difference in atomic mass. Here we have a case of atoms differing chemically by one unit *place* in the periodic table, yet their atomic masses are substantially the same ; so that a chemical difference becomes evident though there is no appreciable difference in mass or atomic weight. Such atoms have been designated *isobares* (from *isos*, equal, and *baros*, weight, i.e. equal in weight), as they would not fall into the same place in the classification and yet they would be substantially of the same atomic weight. It is obvious that the atom contains both electrons and positive charges and the electrical state of the atom arises either from the addition or the subtraction of these quantities. A further example, as in the case of radium, will make the α -particle or α -ray change clearer for, when the expulsion of a helium atom takes place, the atomic number of radium being 88, it is necessary to subtract the atomic number of helium, this being 2 ; then $88 - 2 = 86$. 86 is the atomic number of the lacuna containing radium emanation.* This, of

* Radium emanation is now known under the new name of radon (Rn). This is a better name, since the word *emanation* implies in this connection the property of emitting emanations or radiations, whereas 78 per cent. of the radio-elements emit radiations (see Table VII on p. 96). Sir Wm. Ramsay's name, niton (Nt), got over this difficulty, but the other two inert gases are now brought into line by the new names, actinon and thoron, thus completely eliminating the use of the word "emanation" in connexion with them.

course, means that the resulting atom is this emanation, which is the case, as above stated. Another fact of interest is the change in mass of the atom when it expels an α -particle of mass 4. In this case the resulting atom is reduced in mass by 4 units of atomic weight. . . .

Aston, by means of his improved positive-ray method, has been able to ascertain the masses of many individual atoms, and it was found that a considerable number of the ordinary elements were composed of atoms which were themselves integers differing in mass by whole-number units ranging from one to nine in number, as will be seen from Table I. Such elements are not, therefore, homogeneous in their mass units (atoms). Carbon, nitrogen, oxygen and fluorine appear to be homogeneous in this respect; and there are others of this type given in the table.

Considering now the optical spectra of certain lead isotopes, these have been examined by Aronberg (1918) and Merton (1920), with the result that there is only a slight relative shift in the principal lines, otherwise identical—so slight is the “shift,” in fact, that it is barely measurable.

Another line of research by Moseley brought to light the remarkable fact that each atom common to a given place in the periodic table had a definite and identical X-ray spectrum; that is to say, it was the same for each isotope and, moreover, that this spectrum underwent a regular stepwise change in passing from the atoms of one atomic place to those of the adjacent one, so that all the elements could be assigned definite places in the periodic classification; thus showing that these lacunæ or pigeon-holes are representative of the electrical changes in the structure of the atom taken progressively through the series. This latter fact is in accordance with the existence of isotopes and isobares, and it makes, moreover, the electrical status of the atom also its chemical characteristic; in other words,

12. THE CHEMICAL ELEMENTS

the chemical properties of the atoms are due to their electrical states. Referring to the periodic classification the recurring types of atom may be traced to the recurrence of the electrical state. In order, therefore, to classify, or in a sense index, the elements (i.e. their atoms) it is necessary to assign numbers to the periodic places, as indicated by Table II, and therefore all atoms or isotopes that fall into a given place are assigned a definite *atomic number*. These numbers are given in Table I.

There is, however, a consecutive series of elements known as those of the rare-earths which have in common with all the other elements regular X-ray spectra differing in step-wise fashion, yet these elements are all more or less alike chemically, but they can with some difficulty be separated from each other by chemical methods, and these qualities do not harmonize with those of the other parts of the periodic table or classification in which a change in atomic number corresponds to a change in chemical properties. Attempts to solve this riddle have been made, but up to the present no very satisfactory solution has been offered. A similar irregularity occurs with those elements such as iron, cobalt, and nickel, which fall into Group VIII in the periodic table. There is evidently some other superposed factor which has not been fully elucidated, but which, when cleared up, will give a satisfactory explanation of these irregularities. Langmuir's treatment of this problem, which is given fully in the present author's "Atomic Theories," points to a possible solution of this difficulty, and it is well worth careful study.

Referring to Table I containing the isotopes, it will be seen that they are all put down as whole numbers, and so far as the mass measurements have been made they are so near to whole numbers, with the exception of the isotopes of tin, that the whole-number rule may be regarded as *substantially* true; but, of course, it would not be surprising if small

irregularities were revealed. The isotopes of tin are of particular interest, and on that account a statement of the later work by Aston is here given.

Aston has announced in *Nature* * that he had succeeded in determining what appears to be *all* the isotopes of tin, by increasing the sensitiveness of the photographic plate used, there being no fewer than *eight* of these masses, viz. :—116, 117, 118, 119, 120, 121, 122, 124. Using two of the xenon lines for comparison, the tin isotope (120) contained in the compound SnCH_3 ($= 135$) does not fall exactly midway between the xenon lines 134 and 136, thus indicating that this isotope is apparently a departure from a whole number. Aston states that all the tin values deviate perceptibly from integers by about a quarter of unity; so that taking the highest-mass isotope of the series, its mass might be *about* 123.75—to give an illustrative figure.

This appreciable departure from the integer value exists for *all* the other isotopes of tin, since their step-wise spacing is by *accurate* whole-number units measuring each way from the test value above. We are here reminded of Soddy's statement, namely : "The question naturally arises whether some of the common elements may not, in reality, be mixtures of chemically non-separable elements in constant proportions, differing step-wise by whole units in atomic weight. This would certainly account for the lack of regular relationships between the numerical values of the atomic weights." It will be seen how accurately this statement fits the present case of the isotopes of tin.

These departures from integers raise important issues. Are these departures due to some peculiarity of the atoms or molecules in connection with Aston's deflection method? Or do these departures involve *real* fractional masses of appreciable magnitude?

* June 24th, 1922.

in Table VIII on page 107; but Rn could be used to characterize the place equally well. Pa might be substituted for UX₂, but its quantity is small, as it arises from a branch of small relative magnitude. (See Table VII.)
The occasion of splitting the above table into *blocks*, as indicated, arises from a number-study given on pages 21, 24.

Further Explanation of Table II

In this table the usual group places are indicated by the Roman numerals. The Arabic figures indicate the electrons in the atom, which become the atomic numbers (see Table I) when added as indicated. A represents the electrons in the inner part of the atom which do *not* function in chemical reactions or combinations. B represents the electrons outside of A which *do* more or less function in chemical reactions or combinations: or at least the outer ones up to 8 do.
Each symbol stands for a *place* which may contain isotopes, thus:—

<div style="border: 1px solid black; padding: 5px; width: fit-content; margin: 0 auto;"> <p>At. Wt. 6·94 Isotopes 6 and 7 Atomic Number 3 (or 2 + 1)</p> </div>	<div style="border: 1px solid black; padding: 5px; width: fit-content; margin: 0 auto;"> <p>At. Wt. 39·10 Isotopes 39 and 41 Atomic Number 19 (or 18 + 1)</p> </div>	<div style="border: 1px solid black; padding: 5px; width: fit-content; margin: 0 auto;"> <p>At. Wt. 14·008 No isotopes Atomic Number 7 (or 2 + 5)</p> </div>
Li	K	N
	etc. . . .	etc. . . .
	or in some cases no isotopes thus:—	

This table is based upon a similar one constructed by Langmuir in elucidation of the Lewis-Langmuir theory of electrons, valency relations, etc., which are supposed to govern the chemical and physical behaviour of the elements either singly or in combination, or even in a state of ionization.

It will be seen that the numbers indicated by the letter A are those of the inactive gases, representing the electrons corresponding to the At. No. of these elements. This series of numbers, 2, 10, 18, 36, 54, and 86 may be derived from the following equation, due to Rydberg:—

At. No. inert gases = $2(1 + 2^2 + 2^3 + 3^2 + 3^3 + 4^3 + \dots)$

Stopping off at each squared term gives the above values thus:—

$$\begin{aligned} 2(1) &= 2 \\ 2(1 + 2^2) &= 10 \\ 2(1 + 2^2 + 2^3) &= 18 \\ &\text{etc.} \end{aligned}$$

Cesium has apparently only one value, 133,* yet the atomic weight obtained by the chemical method of analysis is 132.81. Perhaps this individual value will turn out to be 132.8 to harmonize with the tin values. On the other hand, an additional lower-mass atom may be revealed by the use of more sensitive plates, in which case 133 may be a whole number without any appreciable decimal fraction. . . .

It is of passing interest to note that the lead isotopes, including those of radio-active origin, would probably be about equal in number to those of tin. Has there been some disintegration process that is now completely finished and which has left as its only heritage seven tin isotopes? If this speculation should prove true, perhaps nearly all the isotopes are really due to a backward process, if it may be so described. That is to say, if the atoms produced by such a process could be eliminated from the complete list, there would be no isotopes in the duplicate or multiple sense of the term. Whatever may be said, the subject is full of interest experimentally and speculatively, for we live at a time of great activity in both fields, and no doubt there are many surprises in store.

NOTES ON ATOMIC THEORY

ELECTRONS AND PROTONS

Mention was made above that the chemical properties of the atoms were determined or conditioned primarily by their electrical states. This idea gains strong support from the theory of atomic structure, inasmuch as the atoms appear to be built up with units of positive and negative electricity, but to state the theory cautiously, it would be better

* The positive-ray deflection method of Aston is accurate to about one part in a thousand, so that for an atomic mass of 100 the error might be written thus: 100 ± 0.1 .

to say that the atomic constituents were *electrons* and *protons*,* since the proton is the positive charge (or positive electron) associated with a mass unit of *about* the same, if not *the* same, as that of the hydrogen atom taken without its normally attendant electron. Whether the positive charge as such will ever be separated from the "stuff" out of which this unit appears to be made is doubtful, for it may turn out that these two conceptions are but aspects of one and the same thing. The positive electron as such might be regarded as the true counterpart or mirror image, so to speak, of the negative electron; but the proton is not a true counterpart or mirror image of the electron, since it has properties (e.g. a relatively large mass compared with that of the negative electron) which seemingly differentiate it in a remarkable way from the negative unit or entity. Perhaps it is in the nature of things that there should be no *true counterpart* to the negative electron—that, in other words, there must be a relative difference in more ways than one.

ATOMIC NUMBER

The atomic number can be defined fundamentally by sketching a sort of picture of the atom and its changes as revealed by radio-active phenomena. See Chapter XII, p. 95. For purposes of a simplifying assumption consider the nucleus, or a central core of the atom, as composed of protons and electrons in close union, but the former to be in such quantity electrically relative to the latter that a resultant positive charge corresponds exactly to the atomic number. Consider the outer electrons as more or less neutralizing this electrical number which gives rise to more or less different types of elements (atoms).

* A term suggested by Sir E. Rutherford; the term proton takes the place of the term *nuclear unit* used to describe the sub-atom (other than the electron) that forms a part of the ordinary atom taken as a whole.

It will be seen that the atomic number could then attain to high values, the highest value known being 92. When the atom changes radioactively the nuclear charge is altered by the expulsion of α - or β -particles (see Table VII on p. 96). Probably this alteration in the nucleus causes a corresponding alteration in the "electrical arrangement" of the outer electrons of the atom; hence, as in the case of radium, a metal of Group II, changes into an inert gas, of Group O, when its nucleus throws out explosively an α -particle; for, then the outer electrons re-arrange themselves in accordance with the new electrical state impressed on the atom, which means in this case that the atom as a whole becomes electrically neutral. In most cases the atomic number serves to define the atom, or the element, but in the instance of the rare-earth elements this "definition" breaks down as it does not correspond with the definitions obtained elsewhere in the table. It is, therefore, safe to assume that the atomic number simply defines the position of the atom in a sequence of numbers from 1 to 92, for these numbers are the atomic numbers. As the atomic numbers are determinable by the X-ray spectra (see p. 49), it is probable that these spectra have their origin in the more central parts of the atom in that it is, as it were, anchored to the nucleus taken as a central point within the atomic structure. One could almost say that the atomic number is the nuclear number as based upon centric spectra. Completely to define the atom, or the element, the atomic number and the outer-electron arrangement must be taken into account; moreover, as a further refinement in definition, the isotopes and their proportionate numbers may be considered, as when the atomic weight, involving a whole number and a large fraction, for example, is analysed.

CHAPTER II

CERTAIN NUMERICAL RELATIONS IN THE PERIODIC CLASSIFICATION OF THE ELEMENTS AND A FEW OBSERVATIONS CONCERNING THEIR CHARACTER

BEFORE entering into a further study of the elements the following paper, which appeared in the *Chemical News* of July 26, 1912 (vol. CVI, p. 37), will be given as a sort of introductory statement ; but it should be borne in mind that this early publication is not put forward as being in itself of especial importance. It has, however, a certain historical interest in pointing the way towards later developments, particularly in respect of the number of elements existing.

"The perfect inertness of the argon gases has been explained by assuming that negative electrons are firmly held to the atom, and that there are no free bonds of affinity.

"However this may be, the position of helium in a series comprising the strongly basic or alkaline elements of Group I, as given below, suggests that helium is in some way fundamentally of electro-positive make-up.

"It will be seen that the regularity in the *differences* apparently justifies the inclusion of helium in the strongly electro-positive group (see Table, p. 20).

"It must also be remembered that argon, potassium, and calcium are so nearly alike in atomic weight as to suggest some intimate connexion between them.

"Whatever these numerical relations signify, there seems to be a strong indication that the inactive gases are, in some way, more related to the elements

20 THE CHEMICAL ELEMENTS

of Groups I and II than to any other groups, and the great physical and chemical difference is perhaps to be sought in the influence of the electrons, which are bound up with the atom. It may, however, be said that the elements of Group VII claim some recognition in the matter of relationship. . . .

"The following statement is a further argument in support of the idea that helium is fundamentally electro-positive in make-up.

"One must grant that, chemically and physically, there is a big step between the alkali metals and the elements of the argon type. Therefore, the latter are to be considered as a distinctive group comprising

Elements.	At. wts.	Differences.
Hydrogen	1	—3
Helium	4	—3
Lithium	7	—16
Sodium	23	—16
Potassium	39	—46½
Rubidium	85½	—47½
Cæsium	132½	

about 8 elements. If there are more, then they may possibly be associated members or components of those of great magnitude, such as the emanations. . . .

"The elements forming Group VIII are also distinctive, and in all there are 9. Copper, silver, and gold form the end-row members of a rather distinctive grouping,* numbering, when complete, 20 or 21 elements.

"The next and last grouping is a characteristic one, in which the alkali metals are the corresponding

* The term "grouping," in itself an inadequate term, here and elsewhere connotes a collection of groups (in contradistinction to the term *group*), being thus understood from the context where it so admits.

end-row members, which, when complete, should probably comprise only 43 elements, including hydrogen, since the rare-earth elements, as pointed out some years ago by Brauner, form a quite distinct group. The lower part of the table of this grouping after Brauner would be conveniently shown thus :—

						→(Pr, Nd, &c. = 13)
(5th Series)*	Cs	Ba	La	Ce	Ta	W —
(6th Series)	—	Ra	—	Th	—	U —

"We, therefore, have the numbers, 8, 9, 13, 20, and 43, answering to well-recognized groupings, *falling in the order of their average chemical activities.*

"These numbers (N) may be expressed closely by the equation—

$$35 \left(1 - \sqrt{\frac{a-n^2}{a}} \right) + \frac{a}{2} = N \dagger ;$$

in which n assumes the successive values :—0, 1, 2, 3 and 4 ; and $a = 16$.

"This series gives differences :—1(= H), 4(= He), 7(= Li), and 23(= Na), the sum being 35(= a constant in the above formula, which, of necessity, is the sum of the differences). From this series it is natural to suspect that helium might possess latent properties analogous to the other elements which appear to identify themselves with this scheme. However, the sequence may be accidental. Very unstable radio-active elements or products have not been counted.

"Apart from the question of helium being electro-positive in make-up, the above groupings strengthen the view expressed in different quarters by several chemists that some of the older tables contained too many gaps.

* Owing to the assignment of the more noble metals (Cu, Ag, Au, etc.) to a separate group, the serial numbers are altered.

† The calculated values are 8.00, 9.20, 12.73, 19.90, and 43.00. Sum = 92.83

"The term electro-positive may be interpreted in a general sense, namely, as signifying some similarity to such elements as hydrogen, lithium, sodium, etc. In the case of helium, the principal characteristics necessary for a proper identification in this respect appear to lie dormant. It is as if the electrons completely neutralized the electro-positiveness of the element, if such a term may be used.

"In considering the division of the groups as here indicated, it should be remembered that the periodic tables of Mendeléeff and others involve the bringing together, or separating, of a few elements which are respectively dissimilar or allied, as if some disturbing factor prevented a perfect continuity of type. For example, manganese is not altogether in fitting sequence to chlorine or fluorine in Group VII. If an opinion may be ventured, it seems better to give preference to the most regular and natural order of arrangement by atomic weight, and seek rather for the cause of the irregularity than to attempt to make an arrangement that is somewhat artificial from this point of view. The special arrangements are, nevertheless, of practical use, but they should not be adhered to too closely when attempting to trace out new fundamental causes; at least, both views should be considered.

"The process of radio-active disintegration supports the idea that the elements were in general laid down in a consecutive order by weight, but implications of this kind are by no means certain; the elements may have been evolved in groups, as indicated above, by some cyclic process, the return phases sometimes laying down elements that fall in between those previously laid down. It is as if certain materials were exhausted during each cycle or phase, and only upon the reformation or reappearance of such materials could the repeating process proceed or become productive, the character of the cycle as a whole being determined by the quantity of material avail-

SUMMARY AND ADDED NOTES 23

able each time. This is but a suggestion, thrown out to open up fresh lines of thought in connexion with the numerical relations given, and is at best obviously only a crude guess."

SUMMARY AND ADDED NOTES

From the point of view of the inquiries to follow, this chapter refers mainly to the number of rare-earth elements; particularly that there should be 13 elements from praseodymium to the end member of this series; and that there has been a tendency to provide more places for the elements in the periodic table than seems probable from this study. The binding of electrons to produce inertness in the atom is briefly touched upon.

Notes—Recent X-ray analyses made by Coster and Hevesy* seem to indicate that the element of atomic number 72 next to tantalum is a chemical analogue of zirconium, in which case the 13 elements of the rare-earth series would include one of atomic number 61,† so that if the calculations above given have any significance they should include a few unfilled gaps or lacunæ. According to the groupings suggested the following places or lacunæ should exist. The term *lacuna* is used in the sense indicated in Chapter I, i.e. when it is more or less filled it represents the element so filling it; but when not so filled, it represents the type of element that would be eligible for the place. This term appears suitable, as in so many cases the exceedingly small quantities of some elements in existence seem to imply a deficiency in the "process of filling," so to speak. Pro-

* *Nature*, Jan. 20, 1923; *Journ. of the Soc. of Chem. Ind.*, March 16, 1923. These experimentalists suggest calling this element "hafnium" with a symbol "Hf."

† This element may be eventually discovered, but it should exist only in small quantities compared with the quantities of those elements round it in the periodic table.

24 THE CHEMICAL ELEMENTS

ceeding with the groupings, the foregoing calculations give the following results:—

Group O *	8	These groupings are indicated in Table II on page 14.
Group VIII	9	
Group: Pr, Nd, 61, Sa, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu	13	
Grouping: Cu, Ag, Au, to Br, I, 85	21	
H, Li, Na, K, Rb, Cs, 87, to F, Cl, Mn, 43, Ce, 72, Ta, W, 75, 87, Ra, Ac, Th, UX ₂ , U	43	

The appearance of bromine and iodine in a grouping distinguished from one containing fluorine and chlorine appears to upset the above arrangement, but on referring to Table VI, on p. 34, it will be seen that this is as it should be, for the coincidence in the levels follows of necessity where they reach a maximum height. In other words, Table VI gives in many respects a rational interpretation of this system of grouping. Table VI is developed from Table II, shown on p. 14.

* Including three emanations (An, Tn, Rn; see pages 96, 97, 98); or these characterize *one* place, and the *electron* and *proton* at the top of the group make up the number to eight. There would then be two sub-atomic elements, so to speak, plus ninety-two more or less stable combinations of these (protons and electrons) constituting the *normal* elements in terms of atomic numbers.

CHAPTER III

THE MISSING ELEMENTS IN THE PERIODIC TABLE

FROM the previous chapter it will be seen that reasons are deduced for supposing that the rare-earth elements from praseodymium to the end member, taken inclusively, number 13. The coincidence in values made use of in the foregoing study in support of the number relations is not in itself wholly convincing; but when considered in the light of further observations it may be taken as a pointer set in the right direction.

Referring to Table II on p. 14, which is similar to the one given in the writer's book "Atomic Theories," p. 162, it will be apparent that 12 identified rare-earth elements form a distinct group, as is well known; but, in order to have 13 elements to fit the places demanded by the atomic-number sequence, one with an atomic number $54 + 7$ is necessitated. This one has not been discovered. This table is based upon a similar one constructed by Langmuir in elucidation of the Lewis-Langmuir theory of electrons, valency relations, etc., which, it is suggested, govern the chemical and physical behaviour of the elements either singly or in combination, or even in a state of ionization. On p. 15, Notes are inserted below the table so that its general utility and comprehensiveness may be more fully appreciated.

In the table above referred to, it will be seen that the numbers indicated by the letter A are those of the inert gases, representing the electrons in the respective atoms of these elements. This series of numbers,

Commenting on this peculiarity, both places represent extremes in chemical activity, except that the one of the rare-earth group might not represent as much activity as the corresponding one above it. This transition in properties is not unique in the table. The position of manganese below chlorine is a striking example; but it must be remembered that in all probability the curve of change, if it may so be expressed, is very steep at this point, as is the case in some other parts of the table; in fact, this transition in properties occurs elsewhere along the same series, e.g. chromium, a metal in some respects not like sulphur. This form of table has to be read in a cross-wise direction, so that F, Cl, Br,

TABLE III

At. No.	Diff.	Series,
87	_____ 2	$2(1) = 2$
85	_____ 10	$2(1 + 2^2) = 10$
75	_____ 14	$2(3 + 2^2) = 14$
61	_____ 18	$2(5 + 2^2) = 18$
43		

and I are taken together, but this cross-reading disappears on approaching the elements of Group I. This is fully elucidated on the basis of "levels," as shown on page 34. On this account, where the rare-earth elements cross Group VII, there would be no element closely resembling the halogens, assuming the existence of this element. For this reason, the chemical activity here referred to has to be interpreted in a way not perhaps fully appreciated as yet.

If now the atomic numbers of all these missing elements be tabulated, it will be noted that there is a certain regularity in the differences. Table III shows this regularity, which is expressed mathematically after the manner of the Rydberg equation

28 THE CHEMICAL ELEMENTS

given above; but, to state matters cautiously, the arithmetical treatment here given does not represent a true series, as would be the case if the lowest value were 6 instead of 2 (cf. Table IV). However this may be, the regularity on the whole seems sufficiently striking to be of suggestive interest.

It would therefore seem important to distinguish between a process which, when it operates, follows a given law, and the evidence that such a process always produces something. The law may be rigorously true, as in the case of the Moseley-van den Broek sequence; but, and this is the point to be

TABLE IV'

At. No.	Diff.
93	2
UX ₂ = 91	6
85	10
75	14
61	18
43	22
Sc = 21	

noted, the material which was necessary for the production of the elements may have been at times "insufficient"—in some unknown way, perhaps one involving instability of some kind—to give expression to the law, so that lacunæ may exist which represent comparatively few atoms formed, or, in rare instances, none at all.

It is obvious from this study that these missing elements will never be discovered, or if they are discovered their quantities will be extremely minute.

In conclusion, it might be worth while to bear in mind the series given by Table IV, for it involves only one discordant gap which further investigation

of the radio-elements might remove, though at present this seems unlikely. It is of possible interest to note that, the atomic number 93 represents a limit to the series, 92 being the highest atomic number known. Extending the series in a downward direction, as shown, would involve the atomic number of scandium, and this element is known to exist only in very minute quantities relative to the quantities of those elements on each side of it.

UX₂ also exists in quantities relatively small compared with the radio-elements on each side of it. (See remarks under Table II on p. 14.)

It will be seen that according to this study the process of element evolution reaches a sort of low state of production at the places indicated by the atomic numbers in the above tables. There appears to be a similar low state of production in the case of the inert gases, their atomic numbers being similarly formulated.

SUMMARY

(1) The absence of certain elements in the 7th places of the periodic table ; (2) the small quantities of scandium in existence relative to the elements on either side of it ; (3) the missing of places I and VII in radio-active changes ; (4) the number of existing rare-earth elements Pr to Lu inclusive being by certain considerations limited to 13, and being in harmony with a blank atomic-number lacuna $54 + 7$; are all accounted for by one or two types of mathematical series based upon atomic-number differences, the series also having a limiting characteristic in agreement with the extent of the atomic numbers. The deduction therefrom follows that these missing elements do not exist, or if they do exist they are present in exceedingly minute quantities. As a branch development of this study, the

chemical and electronic characteristics of the elements (atoms) can be elucidated by means of a table as designed by Langmuir, but arranged on short and long wedges, so that all elements on a given level will be closely allied, while the displacements along a plane will conform to certain electronic states of the atoms. Extending this idea, a third very long wedge would seem necessary, which would include all the remaining elements; but its lower half would be incomplete after uranium, as the limit is fixed by the above-mentioned series.

CHAPTER IV

THE RELATIVE DISTRIBUTION OF THE ELEMENTS IN THE EARTH'S CRUST AND ITS BEARING ON THE PROBLEM OF THE MISSING ELEMENTS TOGETHER WITH A NEWER TYPE OF PERIODIC TABLE

THE conclusions arrived at in the preceding chapter gain support from the investigations of F. W. Clarke and H. S. Washington, of the United States Geological Survey, who have made a study of the average percentage composition of the earth's crust down to radial depths of 10 and 20 miles. These findings are here given. The term *crust* may be taken, where the context admits, to include the atmosphere and the waters of the oceans, seas, etc.

These investigators, on analysing over 5100 samples, found a great preponderance of oxygen, silicon, aluminium, iron, calcium, sodium, potassium, and magnesium over the other elements present. To give expression to their findings, as thus far recorded (further publication is to be expected), use will be here made of the data given in an article by T. Crook, which appeared in *Nature* of August 19, 1922 (p. 253). To this end Table V is given, which agrees with Crook's table, except that the extreme decimal fractions above barium are rounded off to the nearest figure, so as to reduce the labour in setting up the type, for the evaluations are sufficiently approximate to justify so doing.

In this table Column I is the average composition of a ten-mile crust comprising the atmosphere and hydrosphere; Column II is similarly the average

32 THE CHEMICAL ELEMENTS

composition of a twenty-mile crust comprising the atmosphere and hydrosphere; Column III is the average composition of a ten-mile crust of igneous and sedimentary rocks; while Column IV is the average composition of ten miles of igneous rocks.

TABLE V

Element	I	II	III	IV
Oxygen . . .	49.2	47.8	46.7	46.4
Silicon . . .	25.7	26.7	27.6	27.6
Aluminium . .	7.5	7.8	8.0	8.1
Iron . . .	4.7	4.9	5.0	5.1
Calcium . . .	3.4	3.5	3.6	3.6
Sodium . . .	2.6	2.7	2.7	2.8
Potassium . .	2.4	2.5	2.6	2.6
Magnesium . .	2.0	2.0	2.1	2.1
Hydrogen . . .	0.88	0.50	0.14	0.13
Titanium . . .	0.65	0.68	0.70	0.72
Chlorine . . .	0.23	0.16	0.10	0.10
Phosphorus . .	0.14	0.15	0.15	0.16
Carbon . . .	0.14	0.10	0.15	0.05
Manganese . .	0.11	0.12	0.12	0.12
Sulphur . . .	0.10	0.09	0.10	0.08
Barium . . .	0.075	0.078	0.079	0.081
Chromium . . .	0.062	0.065	0.066	0.068
Zirconium . .	0.048	0.050	0.052	0.052
Vanadium . . .	0.038	0.040	0.041	0.041
Strontium . . .	0.032	0.034	0.034	0.034
Fluorine . . .	0.030	0.030	0.030	0.030
Nickel . . .	0.030	0.031	0.031	0.031
Nitrogen . . .	0.030	0.016	—	—
Cerium, yttrium	0.019	0.020	0.020	0.020
Copper . . .	0.010	0.010	0.010	0.010
Lithium . . .	0.005	0.005	0.005	0.005
Zinc . . .	0.004	0.004	0.004	0.004
Cobalt . . .	0.003	0.003	0.003	0.003
Lead . . .	0.002	0.002	0.002	0.002
Boron . . .	0.001	0.001	0.001	0.001
Beryllium . .	0.001	0.001	0.001	0.001
About . . .	100 %	100 %	100 %	100 %

For further particulars, see Crook's article, and the original paper which appeared in the *Proceedings of the National Academy of Science*, 1922, vol. VIII, p. 108.

Crook comments on the above results as follows :
 " A serious defect in the method of procedure on

which the above estimates by Clarke and Washington are based is that it makes no allowance for the relative magnitude of the different kinds of rock of which the lithosphere is composed. They admit this defect, but claim that any errors involved are likely to be compensating (*Journ. Franklin Inst.*, 1920, vol. CXC, p. 770)." However this may be, the percentages given can no doubt be taken as an approximation to the truth in many cases.

It will be seen from this table that there is roughly almost as much calcium as iron in the earth's crust. Similarly, there is on the whole probably more titanium than hydrogen. The elements, calcium and titanium, fall next to scandium, so that the statement that the latter element is present in *relatively* small quantities seems justified.

In Chapter III reference was made to a wedge type of periodic table. This table (VI) is here reproduced in a complete form with accompanying explanatory data; and the elements of Table V are indicated thereon by black spots, so that those which are more abundant may be seen at a glance.

In studying the relations shown, it will be seen that the position of hydrogen is fixed by the concurrence of three significant differences, as given in the series underneath the table. This observation by itself would not have sufficient weight to become a determining factor, since it might be a chance coincidence; but when further factors are taken into account (see the writer's "Atomic Theories," chapter XX, page 151), the position of hydrogen over lithium appears to be in many respects a satisfactory one (see Chapter II of this book), though the artificiality of all classifications must be kept in mind. Nature did not evolve the elements to fit a given preconceived periodic table. The periodic scheme is man's epitome of the resultant effect of the working of various laws or forces in which *periodicity of action*

X-rays ; for the K, L, M, N series of lines are supposed to originate respectively in, or rather in connexion with, different energy levels. There may be a relationship between these two ideas (they may be two aspects of one and the same thing), but until such a relationship is clearly established it is better to regard them as different factors in this treatment of the subject.

The "levels" shown in the table are not intended to be final as regards adjustment, as this would entail a very thorough knowledge of the properties of a few of the elements of the rare-earth series about which comparatively little is known. Moreover, we are so accustomed to treat the elements of Group VIII as being distinctive from those immediately on each side of them that this idea may be carried too far in adjusting the level of these elements. Bohr in his "Theory of Spectra" (essays), 1922, on page 70 shows a sort of expanded Group VIII so as to include the following elements : Sc, Ti, V, Cr, Mn, Fe, Co, Ni, and Yt, Zr, Nb, Mo, —, Ru, Rh, Pd. Similarly he introduces another enlargement so as to take in all the elements from La to Pt inclusive. These changes are almost tantamount to smoothing out the wedges containing the steps. In this connexion see Chapter II of this book. It is also of interest to note that from Bohr's studies the element of atomic number 72 should not be a characteristic rare-earth element, but one like zirconium, and this element would be on a higher level, as shown in Table VI on page 34. See in this connexion Chapter II, pages 14, 15. See latter part of Chapter XII where the limiting number 17 is referred to.

SUMMARY

The relative distribution of elements in the earth's crust, according to the findings of Clarke and Washington, is tabulated and shown to support the view

that scandium exists in relatively small quantities compared with the quantities of calcium and titanium situated on each side of it in the periodic table, and this fact strengthens the conception of a significant atomic-number series, thereby earmarking the periodic places where no elements can fall, or if they do fall into such places the quantities will be exceedingly minute. The wedge type of periodic table involving "atomic levels" as well as atomic numbers is illustrated by a perspective drawing. In this connexion, the position of hydrogen over lithium is fixed by the coincidence in two number-sequences shown in the tabulations.

CHAPTER V

THE PRESENCE OF SCANDIUM IN THE SUN, AND MODERN VIEWS CONCERNING THE PROBLEM OF ELEMENT EVOLUTION IN CONNEXION WITH THE FOREGOING STUDIES

STARTING out with the problem of the missing elements in the periodic table has led to the consideration of the quantitative production of certain elements in, of course, relative terms, and this now leads to a consideration of the process of evolution of the elements themselves. The sun is of interest in this connexion, for, according to recent views, the solar activity is one involving their production. This aspect of the problem will now be discussed.

The existence of scandium in the sun—and it may be present there in considerable relative quantities—does not necessarily invalidate the view advanced, namely, that this element may not exist in relatively large quantities compared with that of its neighbours, because, according to recent speculations, the stars are manufacturing elements out of hydrogen, and any element, for example scandium, appearing in relative excess during the process of manufacture or element evolution, may not ultimately remain in the same quantities. The following quotation from Aston's book, "Isotopes" (1922), page 103, bears upon this subject:—

"It has long been known that the chemical atomic weight of hydrogen was greater than one quarter of that of helium, but so long as fractional weights were general there was no particular need

to explain this fact, nor could any definite conclusions be drawn from it. The results obtained by means of the mass-spectrograph remove all doubt on this point, and no matter whether the explanation is to be ascribed to packing or not, we may consider it absolutely certain that if hydrogen is transformed into helium a certain quantity of mass must be annihilated in the process. The cosmical importance of this conclusion is profound, and the possibilities it opens for the future very remarkable, greater in fact than any suggested before by science in the whole history of the human race.

"We know from Einstein's 'Theory of Relativity' that mass and energy are interchangeable (Eddington, 'Time, Space, and Gravitation,' page 146), and that in C.G.S. units a mass m at rest may be expressed as a quantity of energy mc^2 , where c is the velocity of light. Even in the case of the smallest mass this energy is enormous. The loss of mass when a single helium nucleus is formed from free protons and electrons amounts in energy to that acquired by a charge e falling through a potential of nearly thirty million volts. A swift α ray has an energy of three to four million volts, so that the change of packing suggested by Brössler need not be nearly so great to provide the energy needed. If instead of considering single atoms we deal with quantities of matter in ordinary experience, the figures for the energy become prodigious.

"Take the case of one gramme atom of hydrogen—that is to say, the quantity of hydrogen in 9 c.c. of water. If this is entirely transformed into helium the energy liberated will be

$$0.0077 \times 9 \times 10^{20} = 6.93 \times 10^{18} \text{ ergs.}$$

Expressed in terms of heat this is 1.66×10^{11} calories, or in terms of work, 200,000 kilowatt hours. We have here at least a source of energy sufficient to account for the heat of the sun (Eddington, *Brit.*

Assoc. address, 1920 ; Perrin, Scientia, Nov., 1921. In this connexion Eddington remarks that if only 10 per cent. of the total hydrogen on the sun were transformed into helium, enough energy would be liberated to maintain its present radiation for a thousand million years.

"Should the research worker of the future discover some means of releasing this energy in a form which could be employed, the human race will have at its command powers beyond the dreams of scientific fiction ; but the remote possibility must always be considered that the energy once liberated will be completely uncontrollable, and by its intense violence detonate all the neighbouring substances. In this event the whole of the hydrogen on the earth might be transformed at once, and the success of the experiment published at large to the universe as a new star."

It is not quite clear how this energy cycle would work. When, for example, small quantities of H_2 and O_2 are exploded to form water (H_2O) great heat is given out ; but to explode water and get the energy back is impossible, for it is not given to us twice over. If the formation of the elements in the sun is due to the combination of protons and electrons taking place, how can we expect to get back heat already given away in the form of radiation ? This is not probably the true interpretation of the above-quoted statement. It is assumed that if the hydrogen contained in the waters of the earth were united by some temperature and pressure condition as obtaining in the sun, the heat evolved would reduce the earth to a molten mass like the sun. However this may be, if this idea can be harmonized with radio-activity, it would be more acceptable ; in which case one would have to assume that there are independent or locally free protons in the structure of the radio-element (very much as there are free electrons oscillating or revolving round a nuclear part), which

combine explosively to form helium, but such explosions do not seem to extend to adjoining protons, for radio-activity is only concerned with a part of the whole atom—and therein, perhaps, lies our safety.

Moreover, one atom explosion does not seem to set off others, for if this were so the rate of decay of radio-active matter could be hastened by simply concentrating it, or, conversely, delayed by simply diluting it. Rutherford ("Radio-active Substances and their Radiations," 1913, page 341) says: "This is the same as the law of mono-molecular change in chemistry, and expresses the fact that there is only one changing system. If the change [decay] depended on the mutual action of two systems, the law of decay would be different, since the rate of decay in that case would depend on the relative concentration of the two reacting substances. This is not so, for not a single case has yet been observed in which the law of decay was affected by the amount of active matter present." Recent experiments further confirm this view.

Considering now the stellar universe as a whole, at one time it was roughly estimated that there were 50 million stars (suns). These, whatever their number may be, vary in size and temperature, so that the physical condition favourable to the production or degradation of different elements in varying quantities may also vary. Assuming that these at one time or another become most active in the production of elements, the quantitative production per star might vary considerably; in short, there would be many variables.

Other views than the above with regard to the origin of the excessive heat of the sun have been advanced. Prof. J. Joly (*Nature*, 1922, vol. CX, p. 112) has recently suggested that the sun's heat is due to temperature and pressure effects stimulating radio-activity in practically all the

elements favourably situated in this respect. The following from *Chemical Abstracts* of October 20, 1922, page 3433, states this view concisely: "Attention is directed to the probability that if solar heat is supplied from radio-active energy derived from elements which had become radio-active under the extreme thermal conditions prevailing, then such induced radio-activity would be attended with explosive phenomena on a very great scale and of extreme intensity. If this inference is justified, explosive phenomena in suns and nebulae, so far from being unaccountable, must be regarded as inevitable, as being associated with gravitative attractions and the internal properties of the atom." This idea was discussed at considerable length in the writer's "Atomic Theories" (1921), Chapter XXI (or see 2nd edition, 1923).

Sir Wm. Crookes's theory of the evolution of the elements is of interest in this connexion. Quoting again from Aston's book, page 117, he says: "A more attractive theory than the one given above [that *all* the elements are the result of radio-active disintegrations (devolution), but these radio-changes were continued beyond the ordinary limit observed at present] is that the complex atoms of matter have been evolved by the aggregation of simpler atoms. This idea has received a good deal of attention in the past. Crookes (*Brit. Assoc. address*, 1886) remarks on it as follows: 'Let us picture the very beginnings of time, before geological ages, before the earth was thrown off from the central nucleus of molten fluid, before even the sun himself had consolidated from the original *protyle*. Let us still imagine that at this primal stage all was in an ultra-gaseous state, at a temperature inconceivably hotter than anything now existing in the visible universe; so high indeed that chemical atoms could not yet have been formed, being still far above their dissociation point. In so far as *protyle* is capable

of radiating or reflecting light, this vast sea of incandescent mist, to an astronomer in a distant star, might have appeared as a nebula, showing in the spectroscope a few isolated lines, forecasts of hydrogen carbon, and nitrogen spectra.

" 'But in due course of time some process akin to cooling, probably internal, reduces the temperature of the cosmic *protyle* to a point at which the first step in granulation takes place; matter as we know it comes into existence, and the atoms are formed.'

" This vivid picture [due to Crookes] may be brought up to date by substitution of free protons and electrons for the hypothetical protyle. We can imagine regions containing matter where the temperature is so high that not only is the dissociation of atoms from atoms and nuclei from planetary electrons complete, but also protons and electrons are in a state of agitation so violent that even the most stable nuclei cannot be formed. We should have here matter of the simplest form we can imagine, or rather of no form at all, simply more or less neutral electric gas. Such a condition is by no means impossible in our universe, and may actually occur during one of those excessively violent catastrophes occurring in far-distant space and observed by us as a new star.

" By some such cooling process as that suggested by Crookes we easily imagine the free charges combining to form the nuclei of elements. Whether those of heavier elements are formed direct by the charges getting into particular geometrical relations with each other, or whether helium nuclei are formed first and then subsequently coalesce, depends on which theory of nuclear structure is adopted. In any case vast quantities of energy will have to be radiated off, and this radiation may be of such extremely high frequency that it is capable of disrupting nuclei themselves, so that there might

be at this stage rapid and continuous transformations from heavier to lighter nuclei and *vice versa*.

"For the present we are interested in the number of each type of atom which survives. It is obvious that if the conditions of cooling are practically identical throughout the whole mass, there is no reason why the composition of the matter produced should vary. If 3 atoms of Cl³⁵ are formed to every 1 of Cl³⁷ at any one point, the same ratio must hold at every point so that a complex [composite] element of constant atomic weight will be formed. But it is much more likely that different parts of this primordial mass will undergo their transformations under different rates of cooling, etc., so it is worth while inquiring if variation in the mean atomic weight of a complex element is to be expected.

"The quantity of one particular atomic nucleus formed will probably depend (a) on the probability of a certain configuration of charges happening as a chance event; (b) the stability of the particular nucleus formed as the result of that event. Again, to take the case of chlorine, each isotope may be regarded as completely stable, and the relative quantities formed will simply depend on condition (a). Now it is not unreasonable to suppose that this is not seriously affected by different rates of cooling, and in this case the isotopes will be evolved in constant proportion. As we know of no natural process by which the proportion of isotopes can be altered appreciably, the complex elements will have to-day the same chemical atomic weight as when they were first formed.

"... If the matter forming the earth went through a primordial stage such as that suggested above, it certainly did so more than 10⁹ years ago."

This is all very interesting and more or less relevant to the subject under consideration; but, of course, extensive quotation widens the subject beyond the scope of the present argument.

Problems of the kind involved in these studies are very difficult of proper solution, but converging lines of investigation often focus different observations into one common one, and thereby establish quantitative relations which can be accepted as being substantially true. It is important to keep in mind that each line of study may lead to some definite scientific or technical fact of permanent value, though at first it appears strange and contrary to common experience.

SUMMARY

The existence of scandium in the sun does not necessarily invalidate any relative quantitative deduction as to the proportionate amount of this element relative to those on each side of it in the atomic number series; for the sun may be manufacturing or degrading practically all the existing elements, and any excess of one in particular may not appear in large relative quantities in the final state when this process of manufacture and (or) degradation is finished. Quotations from Aston's book, "Isotopes," are given in general support of the main argument. It is incidentally suggested that the danger of the hydrogen on the earth exploding to form helium, etc., is not probable; for if this theory be true in principle, then probably the energy of radio-changes, involving the expulsion of an α -particle, is derived from the explosive combinations of four protons to form helium; but, since other protons in the atom are not exploded at the same time the process is of a very prescribed nature, and therein perhaps lies our safety from such gigantic catastrophes as one line of reasoning seems to indicate as being a remote possibility. It is interesting to observe that from the views given above, the largeness of the radio-atoms may permit of a certain internal

freeness of the protons, very much as in the other extreme the electron is the freely moving entity round the nucleus of the hydrogen atom ; but, against this latter idea may be set the one involving central pressure effects, as discussed in the writer's " Atomic Theories," Chapter XXI.

CHAPTER VI

"PLACE PRINCIPLE" AS A GENERAL FACTOR IN THE PERIODIC CLASSIFICATION OF THE ELEMENTS AS WELL AS IN THE BOHR ATOM INVOLVING QUANTUM RELATIONS

THE foregoing chapters seem to bring out clearly the principle of lacunæ which are not properly filled with elements. It can perhaps be shown—one must write cautiously when breaking away from some of the older ideas—that whatever process operates to produce the elements, and probably their emission spectra as well, there is some predominating factor that governs the quantitative productions, and it may involve a "place principle" which gives rise to quantum relations as in line-spectra analysis.

In the Bohr atom the electrons are supposed to jump from one given orbit to another; but always a quantum multiple of energy is involved; that is to say, the jump from an outer-ring orbit to an inner one is not a gradual collapse so that a continuous change in the radiation frequency takes place, but the jumps are such as to give rise each time to definite spectrum lines, each line representing a monochromatic radiation, whereby one frequency is involved when neglecting the finer analyses due to a relativity effect, the orbits being elliptical, as particularly developed by Sommerfeld.

This may be stated in the following way:—

Let n stand for a whole number, so that by placing it next to a term, the term is to be taken n times.

Let ν stand for the frequency of the emitted radiation, or the frequency of the atomic oscillator

emitting such radiation ; not any frequency, but the particular frequency to be obtained by the energy condition to be stated presently.

Let h stand for a small but definite amount of energy in ergs, so that if we write νh we mean a certain amount of energy in erg. sec., according to the value of ν and h respectively.

Let E represent a quantity of energy, but E_n the energy obtained when E is taken n times (n may be *one* to start with).

Then according to the Planck-energy equation

$$E_n = n h \nu.$$

It will be seen that if n be doubled E_n is a doubled quantity ; therefore the energy is expressible in steps or quanta which are always a whole-number multiple of $h\nu$, for omitting n functionally from each side of the above equation gives the quantum

$$E = h \nu.$$

Now h has been found to be constant whenever it can be evaluated, so that the principles of quantum energy and quantum numbers are thus established. The value of h is 6.55×10^{-27} erg. sec.

In the case of line spectra, particularly that of hydrogen, Bohr's theory is that if in two electronic states of orbital motion the energies are represented by E' and E'' , the electron then in passing from one to the other will emit radiation in quanta $h\nu$, so that $E' - E'' = h\nu$; moreover, that each state, whether that represented by E' or by E'' , is "*stationary*" in that no radiation is then emitted. In this circumstance the energy is not given out as radiation until the electron passes from E' to E'' . It is, of course, obvious that since $E' - E'' = h\nu$, $\nu = (E' - E'')/h$, or $h = (E' - E'')/\nu$. From the point of view of the absorption of energy by the atoms this is supposed only to occur during a transition from one stationary state to another.

These emission spectra are due, in short, to the inward "binding" of electrons, each atom contributing its quota to the line spectrum, for no single atom gives at one time the whole series of lines; and, to pass to a wider problem of the different elements, they themselves are in some measure characterized by the number of bound electrons in their structures.

In the case of spectra there are several factors which have to be taken into account, viz. :—

1. The position of the lines as determined by their frequency.
2. The intensity of the lines formed.
3. The polarization, e.g., whether "circular" or "linear."
4. The orbital positions.
5. The elliptical characteristics of the orbits, etc.

It will be seen that the problem becomes a very complicated one, and in its analysis *quantum numbers* are introduced; but in addition to the foregoing, a *principle of correspondence* has been developed by Bohr. Then again, in another phase of the problem, collision phenomena are studied in which *resonance effects* are obtained, and in connexion therewith there are—

1. Resonance voltages or potentials.
2. The line corresponding to a given resonance potential. This effect is supposed to originate from inelastic impacts of one electron against another, and upon analysis the quantum relation rigorously holds true. Ionization and resonance potentials (V) can be determined by the spectrum lines (wave lengths) as the following relation holds true :—

$$V = \frac{hc}{e\lambda 10^8}$$

c = velocity of propagation of light.

e = charge of the electron.

λ = wave length.

h = Planck's constant given above.

Whatever phenomenon of this type is considered, there appears to be a step principle involved, as may be judged from the foregoing. This step idea is also strongly revealed in a wider sense in the instance of X-ray spectra of the chemical elements, particularly as developed by Moseley; for in passing from element to element when they are arranged in the order of their atomic numbers (see Chapter I), they reveal simple line spectra* when they are excited so as to produce X-rays, and the lines appear shifted by regular progressively increasing amounts in passing from element to element. The steps increase by such amounts that by taking the square root of the radiation frequency, as represented by the position of a principle line in each case, and plotting it against atomic-number place, a straight line is obtained. There is therefore something answering to the idea of a "place principle" in the case of—

1. Periodic Table; or Atomic-Number Sequence.
2. X-ray Spectra.
3. Bohr Atom.

If the X-ray spectra be taken as a guide, it will at once be apparent that the large line displacements, which represent the step frequencies, have to be reduced by taking their square roots in order to get a uniform equal-step arrangement, which is, by the way, in agreement with the atomic-number places, or the places in the periodic table. In other words, the atomic numbers cannot be squared and then grouped as they are in existing tables. A square-root term means that there are either two numerically equal factors multiplied together (equivalent to additions as many times as the figure to be added itself represents), or there are other factors involved which are related to one another in a progressive way. What are these factors?

* Each principal line is a member of what might be here termed a local series.

Proceeding with the argument, referring to Table VI on page 34, it will be seen that the "atomic levels" show in general a progressive rise upwards; but this feature is not sufficiently uniform to suggest that it might be one of the above-mentioned factors—whatever they may represent in the atomic edifice. Moreover, the gaps in the periodic table which are unlikely to be *properly* filled stand for a factor that would introduce an irregularity, even supposing that the levels were such as to supply the other factor. It seems, however, significant that both in the atomic levels and in the atomic-number sequence there are depressions or differences which seemingly, like the stationary states in the Bohr atom, have to be bridged by a quantum theory. The "gaps" in short, must be bridged by jumps. If now the stationary states of the atom can be connected with the energy levels, as has in some measure been done, then as a corollary the atomic levels and the atomic numbers are similarly connected.*

Quoting from Bohr's essays, "The Theory of Spectra," 1922, page 118, he says: "We must therefore assume that the energy levels corresponding to the absorption edges [X-rays] indicate to a first approximation the amount of work that is required to remove an electron in one of the inner groups completely from the atom. The correspondence

* It must be remembered that, in all the phenomena considered in arriving at the properties and structure of atoms, they involve different intensities of action. A line spectrum is only produced when a certain very intense electro-mechanical disturbance takes place. The chemical properties of the elements are deduced from their behaviour towards one another, in which case their final state of combination or ionization is either comparatively steady or comparatively quiescent. For this reason it will not be possible to translate all relations in terms of equal status for comparison. It becomes necessary, therefore, to work out generalizations first, and afterwards try and understand their more precise functions by systematic refinements of analysis. We have here, as it were, laws within laws, but the same general principles seem to apply.

principle also provides a basis for understanding the experimental evidence about the appearance of emission lines in the X-ray spectra due to transitions between the stationary states corresponding to those energy levels." It is desirable here to explain that the formulation of spectra in terms of energy E' and E'' (see above) of necessity involves the idea of energy levels answering to geometrical positions of the electron, or electrons, in the atomic structure.

The *correspondence principle* is an important idea here, for it will be seen that the quantum theory thereby takes on a new meaning in connexion with atomic phenomena. It will therefore be desirable at this juncture to give some explanation of this principle, as developed by Bohr.

It is well known that the quantum theory as applied to spectra involves energy conceptions which are not in agreement with the principles underlying mechanical and electrodynamical theory, serving to co-ordinate practically all ordinary mechanical and electrodynamic phenomena. It is possible, however, to avoid in some respects this want of harmony between old-established ideas and the newer one, broadly involving the quantum theory, by introducing the conception of harmonic oscillations in the atom containing the electrons as the main operators which represent the transition states above described. Bohr on page 82 says: "The possibility that a particular transition shall occur may be regarded as being due to the presence of a definitely assignable 'corresponding' component in the motion." Further, he says: "This principle of correspondence at the same time throws light upon . . . the relation between the number of quantum numbers, which must be used to describe the stationary states of an atom, and the types to which the orbits of the electrons belong. The classification of the types can be based very simply on a decomposition of the motion into its harmonic components. . . .

The simplest example of such a conclusion is obtained by considering an atomic system, which contains a particle describing a *purely periodic orbit*, and where the stationary states are characterized by a single quantum number n . In this case the motion can according to Fourier's theorem be decomposed into a simple series of harmonic oscillations whose frequency may be written $\tau\omega$, where τ is a whole number and ω is the frequency of revolution in the orbit. It can now be shown that a transition between two stationary states, for which the values of the quantum number are respectively equal to n' and n'' , will correspond to a harmonic component, for which $\tau = n' - n''$.* This throws at once light upon the remarkable difference which exists between the possibilities of transitions between the stationary states of a hydrogen atom on the one hand and of a simple system consisting of an electric particle capable of executing simple harmonic oscillations about a position of equilibrium on the other. For the latter system, which is frequently called a Planck oscillator, the energy in the stationary states is determined by the familiar formula $E = nh\omega$, and with the aid of the frequency relation we obtain therefore for the radiation which will be emitted during a transition between two stationary states $\nu = (n' - n'')\omega$. Now, an important assumption, which is not only essential in Planck's theory of temperature radiation, but which also appears necessary to account for the molecular absorption in the infra-red region of radiation, states that a harmonic oscillator will only emit and absorb radiation, for

* We are here reminded of the case of two sine waves being compounded into one; or, conversely, one sine wave being resolvable into component sine waves, which are, of course, displaced angularly along the x -axis with respect to each other; but it must not be forgotten that some of these beautiful analyses are mathematical devices which may have no reality in practice. The spectrum lines being a reality, however, we may thus get a glimpse of the actual workings of a beautiful mechanism.—F. H. L.

which the frequency ν is equal to the frequency of oscillation ω of the oscillator. We are therefore compelled to assume that in the case of the oscillator, transitions can occur only between stationary states which are characterized by quantum numbers differing only by one unit, while in the hydrogen spectrum represented by formula (2) all possible transitions could take place between stationary states given by formula (5). From the point of view of the principle of correspondence it is seen, however, that this apparent difficulty is explained by the occurrence in the motion of the hydrogen atom, as opposed to the motion of the oscillator, of harmonic components corresponding to values of τ , which are different from 1; or using a terminology well known from acoustics, there appear overtones in the motion of the hydrogen atom."*

The reader should refer to Bohr's book for further information as it is impossible to detail the very complex subject of spectrum analysis here, but other statements on pages 27-29 may be noted in connexion with the foregoing, especially in reference to the correspondence principle.†

The spectrum to be expected on the basis of the quantum theory and the one to be expected on the ordinary theory of radiation afford an interesting comparison. Where we are led to suppose that the stationary states agree, that is to say, in the region where the states deviate only a little from one another, the theories coincide in predicting a similar result though the mechanism in both cases is different.

* Overtones.—Considering a vibrating system, its lowest-pitch vibration, or its fundamental note, is that vibration which distinguishes itself from a series of higher vibrations or harmonics, and when these are taken relative to the fundamental vibration they are spoken of as *overtones*. Thus the overtones are due to *higher orders of vibration*, as it is usually expressed, while the fundamental note is of the lowest order of vibration, or the one of lowest pitch.—F. H. L.

† The reader will find an interesting review of Bohr's book, by R. H. Fowler, in *Nature*, of April 21, 1923, pages 523-526.

"The different frequencies corresponding to the various harmonic components of the motion are emitted simultaneously according to the ordinary theory of radiation and with a relative intensity depending directly upon the ratio of the amplitudes of these oscillations;" but the quantum theory indicates that the various lines are emitted by a different process, namely, one involving transitions from one stationary state to "various adjacent states, so that the radiation corresponding to the τ th 'harmonic' will be emitted by a transition for which $n' - n = \tau$. The relative intensity with which each particular line is emitted depends consequently upon the relative probability of the occurrence of the different transitions."

SUMMARY

The Bohr atom, based upon radiation phenomena, involves quantum multiples of energy, for the electron is supposed to jump from one "stationary" state to another, at which time radiation is emitted, the process being like a planet revolving in a stationary orbit round the sun, then suddenly jumping to a new orbit which would be described nearer to the nuclear sun, the orbits being elliptical. The elliptical orbit, like that of the planet Mercury, involves a relativity effect, and this, as studied by Sommerfeld, explains the very fine lines, so that there are, as it were, laws within laws, just as there are lines within lines, for a "single" line then becomes upon resolution a composite of finer lines. The energy radiated during, or by, this step process has been more or less completely formulated in the case of hydrogen and helium, the spectrum lines giving the frequencies in the energy calculations. A *correspondence principle* due to Bohr is introduced in elucidation of the process, since the frequencies resemble the overtones observed in acoustics (that is to say, with sound emitting

bodies) which are governed by a certain corresponding "component" of motion of the atom. In the periodic grouping of the elements, and in the atomic-number sequence, steps are involved which have a parallel in the above phenomena. Extending this idea to the "atomic levels," they, like the energy levels in the atom, are significant of a "place principle." This principle is introduced as a general term to illustrate similarity of the phenomena so that the radiation emitted by the above process, involving the "binding" of the electron by nearer steps to the nucleus of the atom, is like the steps obtained in passing from element to element in the periodic table; and this is perhaps best exemplified in the X-ray step spectra of the elements when they are studied consecutively. The nucleus referred to above is a positive entity corresponding to two or more positive electrons (protons) in excess of negative nuclear electrons.* The growth of this nucleus corresponds to the growth of the atom in the evolution of each series of elements in the periodic table; but, in addition thereto, the binding on of outer electrons takes place, judging from the electronic states of the atom in passing from element to element in the atomic-number sequence, as will be seen from the next chapter.

* See atomic number, page 17.

CHAPTER VII

HOW THE "BINDING" OF ELECTRONS IN SPECTRAL ANALYSIS LEADS TO, OR IS CONNECTED WITH, COGNATE IDEAS

THE periodic table shown on page 34 is in keeping with the idea that the elements are built up by the accretion of electrons in connexion with the growth of the positive nuclear part or parts of the atoms, the atomic number corresponding to the *resultant positive nuclear charge* on the Rutherford theory: or according to the *number of electrons in the atom* on the Lewis-Langmuir theory.

The latter theory is more convenient for illustrating both the structural characteristics of the atoms and those of the main table, classifying them, especially from the chemical point of view; but it should be remembered that it would not be impossible, with the present limited knowledge, to substitute positive nuclear charges for negative-electron values in the table and get a very similar result. This would entail introducing the requisite numbers of electrons, but the construction so obtained would be in agreement with Rutherford's theory (see page 17). However this may be, for the present the Lewis-Langmuir theory will be made use of in this study.

Referring to Table VI, on page 34, when passing from element to element along each horizontal row, that is to say, along each wedge, the outer shell of the atom takes on more and more electrons until the thick end of the wedge is reached. Then a sudden drop to neutrality takes place, signifying that

the outer shell of the atom has its full quota of electrons. The atom then formed has no chemical activity, and it becomes an inert gas atom, forming one of the zero members in the table. Continuing the process again along the next wedge, it then becomes the nucleus round which the process repeats, and so on to the end of the table. It is to be noted in this connexion that the table on page 14 is the basis of the one on page 34, and therefore both tables should be consulted. Moreover, the principles defined in Chapter I should be appreciated.

It may now be stated that the elements are produced by the binding of electrons to form nuclear structures. These structures are themselves built up of protons which become bound more or less in the same manner, probably through the agency of electrons. In fact a joint or composite process is evidently involved, so that the number of electrons in the atom which would neutralize the net positive charge of the nucleus corresponds to the atomic number; or the atomic number corresponds to the positive nuclear charge.

This idea of complete neutralization thus becomes in part a convention, for if the positiveness of the atom due to the total positive charge exactly balances the number of electrons, then perfect neutrality should follow in *every* case, since the opposite and equal electric charges involved would neutralize each other; whereas, only the inert gases possess fairly perfect neutrality if electric neutrality is to correspond to chemical inertness, as is supposed to be the case. The principle of ideal or perfect neutrality, obtaining only when the proton and the electron can come together so that their common field will contract to nothing, must be kept in mind. In practice this union is not probable (see Chapter XIII, page 113); consequently there are differential effects due to the geometric structure involved, and these differences would in some measure account for the variety of

atoms and their chemical characteristics, but in addition to this second-order effect, as it may be termed, is the first-order effect due to loss and gain of electrons in the outer shell of the atom. It must be remembered that many of the elements (atoms) are studied in the compound where the average polarity is practically zero, as stated in the next paragraph. This observation does not, however, apply when the elements are considered specifically as atoms, but it is well to keep this distinction in view.

Between the inert gases lie various types of elements which strive, according to the Lewis-Langmuir theory, to become neutral by combining with one another so as to bring the electronic charge to a state of neutrality when taken over the whole combination, as in the case of the inert gases of the zero group. The inert gas atoms are not, of course, molecules in the sense that they are molecular like N_2 , but they do possess molecular individuality, as instanced by many other proper molecules which are so inert as to exist in a free state under a wide variety of conditions. To give effect to this neutral combination, the electrons are supposed to be shared between adjacent atoms to complete their octets. Hence the term *octet theory* applied to this view of chemical combinations. The combining proportions, or rather the valency values in vogue, become to a considerable extent rationalized by this theory.

The subject can be made clearer by giving a few examples. The atoms can be studied singly by regarding the extent of their electron deficiency as an indication of their atomic character in the case of all the elements falling between those of the zero group. When this is done systematically it is seen that lithium, for example, has 1 electron in its outer shell, beryllium has 2, boron 3, carbon 4, nitrogen 5, oxygen 6, fluorine 7, and finally neon 8. This final number implies completeness, for the types then repeat. Now 8 electrons equally spaced round the

surface of the atom taken as a sphere would present a certain geometrical structure, since by joining them together by straight lines, at right angles to each other, a *cube* is formed. Hence the *cubic atom* conception. This is, however, a somewhat conventional figure, which has been referred to as an "octet" to indicate that there are 8 electrons in the outer layer of the atom arranged in practically cubic symmetry; and, moreover, it is taken as one which has its full complement of *bound* electrons. A sort of cubic inert standard is thus created, and practically all the other chemically-active atoms are supposed to fall short of this standard, but by their entrance into combination with each other the standard is approximated to in the compound formed, more especially if it is molecular like O_2 , for example.

It is well to keep in mind as a sort of background idea to this conception the probable fact that chemical activity of a given molecular compound will depend upon the ease with which its atoms can be separated; at least this is a factor which should not be overlooked. These matters have been detailed in the writer's book "Atomic Theories," and they need not be elaborated here. It is not the object of this book to give in great detail information already fully treated in other books, but rather to present the ideas in a form which will help the reader to comprehend the trend of modern research and study in connexion with some of the newer advances which have not yet been dealt with in text-books.

Returning to the subject, the reader might at this juncture inquire whether any experiments have been devised which would show that the above ideas are in general true. The experimental work of Rutherford and of Moseley, detailed in the author's book referred to above, affords overwhelming evidence that the atomic number is a real factor in the atom, and that it represents the net nuclear charge of the atom when understood in the manner already

indicated. Moseley's work on X-ray spectra gives the strongest possible support to this conception. In the case of radio-active phenomena the electrical state of the atom affords ample evidence that the theory is at least true in the main; for here are cases of positive and negative charges being ejected by steps from the atom when it expels alpha (α) particles (He^{++}) and electrons (e^{-}), and concurrently therewith the resulting element suffers a change as expected by theory: a chemical and a physical change in fact (see Chapters I and XII).

Now an experiment has been made by A. E. Oxley (*Roy. Soc. Proc.*, 1922, vol. CI, p. 264) which is of interest in this connexion. It has long been known that palladium has the property of absorbing hydrogen in very large quantities, but this action does not produce a compound quite in the accepted chemical sense. On the other hand, it seems to afford an example of the formation of a pseudo-atom of silver; or, taking the atoms collectively as representing the element, a pseudo-*element* of silver is formed. From Chapter I of this book, it will be seen that the atomic number of palladium comes next to that of silver, so that if the former could have its number augmented by 1 it should resemble silver. The addition of hydrogen, which has unity atomic number, to palladium is thus highly suggestive, for it is perhaps a near approach to the actual formation (upbuilding) of an element by increasing its atomic number in a sort of artificial way.

Oxley found that when the absorption took place the palladium lost a good deal of its paramagnetic quality and approximated to silver in being almost dia-magnetic. Now the palladium + hydrogen system involves, as suggested by Oxley, the entrance of the hydrogen atom into the shell of the palladium atom as some such action seems necessary, since magnetism is now supposed to be an atomic phenomenon involving a structural change in the atom.

It is well known that intensely magnetizable metals, like iron, cobalt, and nickel, lose their high magnetic susceptibility when entering into certain chemical combinations with other elements, so that the result of the above experiment is somewhat to be expected. In this case, however, the compound—if it may be so called—is not chemically analogous to other normal compounds, it being distinctly metallic, and on this account the peculiarity revealed seems of importance, inasmuch as it is always of scientific interest to study borderland examples of this kind, since they often point the way to new fundamental lines of investigation.* It will be remembered that the whole science of radio-activity grew out of the phenomena of specks, so to speak; and the theory of relativity arose partly out of effects only just appreciable when very high relative velocities, approaching that of light propagation, were studied. On the more practical side, wireless communication arose from Hertz's early experiments made with a view to testing Maxwell's theory that light was an electromagnetic-wave phenomenon.

It will be seen that all the effects thus far discussed involve broadly *binding processes*, as stated more concisely in the following summary.

SUMMARY AND ADDED NOTE

The periodic table, as an explanation of the evolution of the elements, is in harmony with the electrons entering into the atomic structure by

* In passing from element to element in certain parts of the periodic table the metallic properties persist over a considerable range, whereas, with normal compounds formed of these metals, e.g. iron sulphate, the metallic property disappears; but this is not the case with palladium + hydrogen, so that one is justified in regarding this absorption phenomenon in some way different from ordinary chemical combination; indeed it is more akin to the fundamental changes observed in the elements when passing along the series, as has already been argued. The study of hydrides opens up an important field in the writer's opinion.

successive absorptions or bindings ; and in a similar way the nuclear parts of the atom, analysable in terms of protons, show a like binding process in the general upbuilding of the atomic edifices. This process, moreover, involves quantities of positive and negative electricity which tend to neutralize each other ; and in the zero group this neutralization seems complete each time, for the atoms of the different elements of this group show no chemical activity. Chemical inertness is thus associated with electrical neutrality. The example of the electron growth in the outer shell of the atom is cited, in which case $\text{Li} = 1$, $\text{Be} = 2$, $\text{B} = 3$, $\text{C} = 4$, $\text{N} = 5$, $\text{O} = 6$, $\text{F} = 7$, $\text{Ne} = 8$. 8, being a complete electronic system, it is referred to as an "octet," and the probable spacial arrangement of the electrons in the outer shell of neon is at the corners of a cube ; hence the cubic and octet standard of the completed system is one which is more or less imitated by the elements falling between He and Ne—that is to say, when entering into chemical combination, for they jointly form in effect octets or cubes fully filled with electrons. That this process extends and repeats is evident from the periodic table. There are cases, however, in which extra electrons are supposed to take up polar-like positions whereby the octet is raised to a nonet, etc. In general two electrons are thus supposed to be shared between cubes so as to give rise to completed octets. These "sharing" combinations seem to give a rational interpretation to valency. This is in part the Lewis-Langmuir theory. Now just as these pseudo-inert combinations can be formed which simulate the inert-gas atoms, though more or less imperfectly, so, too, palladium in absorbing or binding a hydrogen atom of atomic number 1 produces a pseudo-silver of atomic number equal to that of real silver, and in this case the magnetic susceptibility of palladium, which is quite appreciable, is diminished by the

addition and approaches dia-magnetic silver in its magnetic quality. This is a borderland example in some respects on a par with chemical combinations of iron, cobalt, and nickel, with other elements, in which case the magnetic susceptibility suffers a profound change, but there is a characteristic difference, as stated above. These views are in agreement with magnetic phenomena having an atomic origin; moreover, they are in harmony with the idea of the elements combining by binding each other, very much as, in the formation of the elements themselves, protons and electrons are successively bound. It was seen that emission spectra result from an electron binding process. The atom formation is an electron and proton binding process, as already stated; and finally the formation of certain chemical compounds is an atom-to-atom binding process, but involving the sharing of electrons, and these virtually become the bonds of affinity, and the valencies of the atoms of the elements, or the valencies in their compounds, are thereby considerably elucidated. Geometrical constructions enter into these processes, as will be made more evident in the next chapter. The reader should not be deceived into thinking that all these statements stand for experimentally-proved facts. In some cases the experimental work merely points the way, and further investigations may lead to modifications in the views here advanced. It is equally important for the reader to avoid going to the other extreme by treating these matters with indifference, for the real object aimed at is to develop useful working theories in order that he may become seriously interested in the subject. A theory is a conventional scheme for linking together more or less isolated facts in such a way as to lead to the extension of knowledge, though the picture so formed may not altogether be a true one; but, in addition, it should elicit interest by the beauty and

comprehensiveness of its design, for it is at its best the intellectual counterpart of the real structure as far as "seen" and measured.

NOTE

Continental physicists have contributed so largely to the modern views of atomic structure that the mention of one or two in particular, as given in Bohr's book (*loc. cit.*) will be of interest, especially since X-ray spectra have been closely studied in this connexion.

The stability of the atom as indicated by Kossel in the case of its X-ray spectrum seems to involve a group structure, so that in this phenomenon the removal of an electron by the action of some external source of energy results in another electron (an inner one) taking its place, and this "change" may occur in "as many ways as there are groups of more loosely bound electrons." Some such action as thus briefly sketched would seem to account for the peculiar absorption phenomena observed. "It has also led to the prediction of certain simple relations between the frequencies of the X-ray lines from one and the same element," and it has afforded a basis for the "classification of the complete spectrum," but conflict with Sommerfeld's fine-line analysis appears at first sight. This discrepancy between the two theoretical investigations has been removed. Another line of study by Kossel similar to that by Lewis and Langmuir calls for mention here.

Bohr, on page 73, in mentioning Kossel's work, says: "If we consider for instance an inactive gas like argon, the atomic number of which is 18, we must assume that the 18 electrons in the atom are arranged in an exceedingly regular configuration, possessing a very marked stability. The pronounced electronegative character of the preceding element, chlorine, may then be explained by supposing

the neutral atom, which contains only 17 electrons, to possess a tendency to capture an additional electron. This gives rise to a negative chlorine ion with a configuration of 18 electrons similar to that occurring in the neutral argon atom. On the other hand, the marked electropositive character of potassium may be explained by supposing one of the 19 electrons in the neutral atom to be, as it were, superfluous, and that this electron therefore is easily lost; the rest of the atom forming a positive ion of potassium having a constitution similar to that of the argon atom." Before continuing this quotation it is of interest to give a few lines from the present writer's little book, "Studies in Valency," 1913, Chapter V: "The ionic theory of Arrhenius requires that a salt, when dissolved in water, should undergo dissociation into *atoms* or *radicals* carrying charges of electricity, and that the positive and negative charges should endow these atoms or radicals with new properties. These 'newly-endowed' atoms, or radicals, termed *ions*, do not themselves appear to combine permanently, although they co-exist side by side in a state of dissociation. In short, they behave towards each other as *inert* substances, owing apparently to the charges of electricity they carry. . . . Another extraordinary peculiarity, that of the argon gases, is here called to mind. These inactive gases possess no valency powers, and they do not combine at all. . . . Consider then, for the purpose of argument, or as a *suggestive hypothesis*, the inactive gases as a special case of free ions, having by theoretical analysis the characteristics of a salt in solution. . . ." It will be seen that the observations of Kossel and Lewis and Langmuir (detailed in the writer's "Atomic Theories") bring the views just quoted to a rational conclusion in the octet scheme already touched upon in this chapter. Returning to Bohr's summary of Kossel's investigations, he says: "In a corresponding manner it is

possible to account for the electronegative and electropositive character of elements like sulphur and calcium, whose atomic numbers are 16 and 20. In contrast to chlorine and potassium these elements are divalent, and the stable configuration of 18 electrons is formed by the addition of two electrons to the sulphur atom and by the loss of two electrons from the calcium atom. Developing these ideas Kossel has succeeded not only in giving interesting explanations of a large number of chemical facts, but has also been led to certain general conclusions about the grouping of the electrons in elements belonging to the first periods of the periodic system, which in certain respects are in conformity with the results to be discussed in the following paragraphs. Kossel's work was later continued in an interesting manner by Ladenburg with special reference to the grouping of the electrons in atoms of elements belonging to the latter periods of the periodic table. It will be seen that Ladenburg's conclusions also exhibit points of similarity with the results which we [Bohr] shall discuss later." Bohr also alludes on pages 74, 75 to the views of Lewis and Langmuir, and the latter's conception that the atom possesses a *cellular structure*.

CHAPTER VIII

CHEMICAL PHENOMENA AS A BINDING PROCESS WHICH IS HERE ILLUSTRATED BY EXAMPLES SHOWING GEOMETRICAL STRUCTURE

IT is one object not to tire the reader by presenting too great a mass of detail, and also to avoid those issues which tend to detract from the simplicity of the general statements. It is, of course, known that practically all theories are imperfect; but in order to get a working analytical basis it is desirable first to present a broadened view rather than one involving much ramification, so that the reader may have before him a general working scheme, knowing all the while that its detailed structure has been elaborated, and further developments will follow, and that some of its main features will more or less be modified in time.

The use of X-rays in the probing of matter has proved to be of great scientific and practical importance, and a few examples will show how powerful this method of analysis is, while at the same time its accuracy cannot be questioned.

It is assumed that the reader is conversant with the general principles of X-ray analysis as detailed in many text-books, so that the treatment here will be confined to a few special cases. It is hoped that the examples given will help to co-ordinate the general trend of the argument as developed in the preceding chapters.

In introducing the subject it may be stated that the action of X-rays on entering crystalline matter is such that the rays, owing to their fineness

—that is to say, owing to their short wave-length—penetrate to the nucleus of atoms, but when the X-ray reaches the particular atomic nucleus, the bull's-eye of the target, so to speak, it is reflected back at an angle equal to its angle of incidence. This reflection is in the form of a new wave-train (diffraction wavelets), which, as groups of these target-like atoms are being dealt with, reinforce one another when in proper synchronous relation. This synchronous reinforcement, as it might be termed, gives rise to tiny pencils of light which, upon striking a photographic plate, produce small elliptical spots*—of course revealed only when the plate is developed.

On examining these "Laue spots," as they are often termed—von Laue having predicted the general result mathematically by considering the atoms as forming a diffraction grating—it was found that their positions were such as to prove without doubt that the atoms of crystals are spaced in a geometric fashion, for the lattice structure already developed in theory was found in the main to be the true picture of affairs; but, of course, many other facts were discovered which the space-lattice theory had not taken into account.

The term *space lattice* is a little misleading, since the drawing of lines from the geometrically spaced atoms, as revealed by the above optical X-ray method, is a convention merely serving to show the nature and regularity of the atomic spacing. The close packing of the atoms results in their "crystal forms" interpenetrating.

One of the most interesting facts which emerged from this line of investigation is the crystalline structure of pure metals, and the structure of these

* The elliptical shape of these spots is due to the angular projection, as may be illustrated by intersecting a round beam or pencil of light by a plate set at an angle greater or less than 90° with respect to the axis of the beam.

metals when mixed together to form alloys; or in more technical terms when in "solid solution." Quoting from E..C. Bain in the *Chemical and Metallurgical Engineering*, Jan. 3, 1923, vol. XXVIII, p. 21:—

"When a metal A acts as a solvent in taking up metal B, in the solid state the atoms of B replace atoms of A in the space lattice. This substitution seems invariably to alter the perimeter of the lattice slightly, but never its type until such a quantity is added as will exceed the limit of solid solubility, at which point a new lattice is formed compatible with the increased atomic ratio. This new phase usually involves the formation of a compound, and the metal begins to assume the lattice characteristic of the compound." The following examples taken from Bain's article are of particular interest. See Fig. 1:—

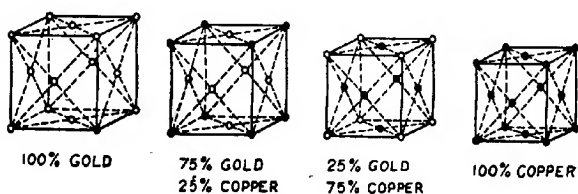


FIG. 1.

NOTE.—In the case of 25 per cent. of gold plus 75 per cent. of copper, for example, the gold atoms form a simple cubic lattice, the corners of which are of the face-centred cube, so that the copper "atoms occupy the corners of three equal systems of interpenetrating cubes."

From Fig. 1 it will be seen that the atoms have taken up definite positions and that they assume collectively symmetrical geometric forms, as obtained by drawing lines in the manner shown. While this example is not so characteristically chemical, as in the case of other well-known examples of crystal

structure revealed by X-ray analysis, it serves to show that processes of binding are involved, but the *places* must exist, otherwise no systematic substitution would take effect. It is therefore evident that a place principle is exemplified, for the two ideas are but aspects of one and the same general process.

It is customary to regard these actions as due to *forces* operating in directional ways, as beautifully shown in electric or electromagnetic phenomena involving *lines of force*. Now the geometry of the atom becomes itself an atomic physics, and groups of atoms give rise to the extension of the properties of the atom. The following, taken from one of the writer's pamphlets ("Definition of the Æther"), is of interest in this connexion, particularly the statement about the atom, which is here thrown into italics.

Considering the æther, "it is difficult *not* to conceive a medium which has remarkable properties. *Properties* which link up the sun and the planets. *Properties* which cause masses of matter to get nearer together, balanced by properties by which they tend to get farther apart if in proper rotation. *Properties* which enable waves of enormous range in variation to be propagated at a fixed velocity through space. *Properties* which enable iron to be attracted to a magnet at a distance, and which enable a motor armature to react with its field, notwithstanding a clear air-gap between the armature and its field poles. *Properties which, when extended to the atoms, link up their sub-atomic parts in such ways as to impart characteristic differences to atoms of different elements, and this becomes perpetuated, though changed, in the compounds formed, making the whole world variegated in consequence.* In short, we are tempted to shift all the final responsibility, so to speak, on to the æther, and simply to relegate to this universal medium the characteristics or properties implied by mathematical equations. This, in a sense, Einstein has done; but we are still left with a desire to know

more about this æther. How then is it defined? Einstein formulates no mechanism at all; he simply endows space with physico-mathematical functions, and co-ordinates many phenomena. Eddington, in his book, 'Time, Space, and Gravitation,' says: 'Einstein . . . deduces a great number of remarkable phenomena solely from two general principles, aided by a mathematical calculus of great power; and it leaves aside as irrelevant all questions of mechanism.'"

We have here come to the "parting of the ways," for, according to the more recent ideas advanced by Einstein, we must give up the *force* idea as expounded by Newton and substitute a *geometric* idea of space, which is, however, modified by the presence of matter in it.

An example will illustrate this mode of analysis. Einstein says in effect that the earth moves round the sun in an elliptical orbit, *not* because the sun is pulling it in all the while with a force, while at the same time its velocity is keeping it from falling directly into the sun, but because the particular path through which the earth moves is the only space-time course possible when the geometry of space is constructed as modified by the presence of the earth and the sun, and consequently the earth's orbit is the least-time track through space; for by Einstein's theory the very foundations of *time* and *space* become conditioned, i.e. altered by the phenomena involved; * in brief, the space-time continuum of the earth's motion round the sun, if it may be so described, involves a corresponding curvature of space.

Since geometry is made the basis of this theory, suppose geometry be reduced to the simplest possible single fundamental conception, it could be said that

* The "observational standpoint" must not be lost sight of in considering these matters, for we co-ordinate knowledge by a system of analysis based upon observational measurement.

it is the science of lines. The reader should understand that this device of expression is one in which a single feature is purposely made to overrule all the other features for purely reasoning purposes. Suppose that the force which turns the motor armature be reduced to a single conception. It could be said that it was due to bent lines of magnetism trying to straighten themselves out, and, in so doing, the conductor carrying the electrons—and which produced the bending—was pushed out of their way; or, in short, was due to the contraction of the lines.*

The dynamo, on the other hand, circulates the electrons in the wire by a reverse action. Therefore the curvature of the line, like the curvature of the earth's path round the sun, is due to the circumstantial influence of matter present, including electrons, and in both cases the movement follows a course of least resistance in the complex of curved space.

The geometry thus becomes merged in the physics of the line, and we may say that in one sense the *line is the thing*. It is not so simple as all this, for the complexity of the "universe," whether it be the atom, the electric motor, or the stellar universe, is certainly appalling; but out of it all some simple constructive ideas may emerge. We begin to see that in the Bohr atom we get a picture of a miniature universe. In the motor the complex of lines, like the active (radiating) atom, gives rise to a process of perpetual but renewed attempts at binding—the wire and its electrons are continually striving to evade the tension of the bent lines, but for every

* This extreme contraction of definition is like the one above for geometry, and it is merely given to throw into relief a factor of importance, in the opinion of the writer; and, moreover, it is stated to secure parallelism of definition, for there is fundamental similarity between geometry and physics, in that they become two aspects of phenomena. The artifice of man's methods must not be lost sight of in considering these matters (note in this connexion Chapter IV, page 33).

effort made restoration of tension automatically takes place: they are always striving to "get there," but they never do in their eternal "round,"—and in the universe the geometric structure of things, as in the gold of Fig. 1, on page 69, becomes visualized on a huge scale. In fact Einstein speaks of the universe as a *cylinder*. We have already seen that the atom is a *cube*, and the periodic table is expressible as a *wedge*. However this may be, there are governing principles involved which may be formulated in terms of geometrical physics, in which the line becomes a geometrical factor, or *vice versa*. This will be made more evident in the next chapter.

Mention was made above of the universe being a cylinder. There is, in the wide problem of relativity in its treatment by Einstein, an interesting development concerning the special extent of the universe, for Einstein regards it as a cylinder. The quantity of matter (density) distributed throughout space enters into these problems. These ideas can hardly be taken as literally true, any more than one can regard every atom as a cube, though cubical characteristics seem to be revealed.

SUMMARY

X-ray analysis is briefly described. An interesting case of substitution of atoms in a gold-copper alloy is illustrated to show the geometric form of the space lattices involved, and also to show that the "binding" of the atoms in the structure implies a "place principle." The newer conception of a geometric attribute of space, as distinct from a force acting from one body to another, is noted in connexion with the structure of atoms or their geometric arrangements in space lattices. By means of a device of contracted reasoning it is shown how geometry is essentially a line construction; and the electromagnetic-line scheme, as in a motor or dynamo,

affords a suggestive parallel, so that the *line*, or the geometry which corresponds to lines, is the important factor; but the ideas here tend to merge and form geometric physics. In passing from the largest geometrical construction, that of the universe, down to the smallest, the atom and its attendant electrons, there appear always characteristic geometrical forms. There appear also to be governing principles which may be formulated in terms of geometry with a physical basis, and the lines of this geometry become geometric in a physical sense. Einstein's contributions in the new physics must be recognized as important, and an example is given above.* The geometry of space is developed by an analogous case in the next chapter, but the reader must be careful to remember that analogies, if nearer the truth than we know, are far from representing the whole truth.

* In casting about for some authoritative statement of the bearing of relativity on the domain of the atom, the following from Eddington's book, "Mathematical Theory of Relativity," page 240, was found: "Can the theory of relativity ultimately be extended to account in the same manner for the phenomena of the excluded domain of physics, to which the laws of atomicity at present bar the entrance? On the one hand, it would seem an idle exaggeration to claim that the magnificent conception of Einstein is necessarily the key to all the riddles of the universe; on the other hand, we have no reason to think that all the consequences of this conception have become apparent in a few short years. It may be that the laws of atomicity arise only in the presentation of the world to us, according to some extension of the principles of identification and measurement. But it is perhaps as likely that, after the relativity theory has cleared away to the utmost the superadded laws which arise solely in our mode of apprehension of the world about us, there will be left an external world developing under specialized laws of behaviour."

It must be remembered that already relativity has made it possible to analyse the fine emission lines of hydrogen and helium. The lines which were originally regarded as coincident were resolved into a configuration of closely associated lines, this being due to the change in mass of the electron in describing its elliptical orbits in accordance with the theory of relativity. See Sommerfeld's "Atomic Structure and Spectral Lines," translated by H. L. Brose.

CHAPTER IX

GEOMETRY OF SPACE A FACTOR IN PHYSICS

THOSE who have studied both physics and geometry must realize that these sciences possess features in common, and that in time a partial blend of the two might be made to the advantage of each singly. Chemical changes, and in particular atomic and molecular phenomena, seem to suggest a basis for this union, for in everything connected with the atom geometric form is recognizable. Physics, however, deals largely with translational activities, such as the movements of molecules as developed in the kinetic theory of gases, and here a departure from the static or rest aspects of geometry is apparent.* The question is, Is the difference real? To say that it is more apparent than real when the proper developments in the two general ideas are made may be the true answer. So far attempts fully to account for atomic phenomena on the basis of kinematics and electrodynamics have failed; at least in such structures as suggested by the Lewis-Langmuir theory, for the positioning of electrons in their relation to each other and to a positive nucleus has not met with complete success. It is true that "approximations" have been made which make use of the forces due to magnetic and

* Of course, we know that a diagram may represent an activity, but the question is not so much that of the successful use of the diagram as the inner meaning of the phenomenon, as will be seen presently.

electrostatic fields round the parts of the atomic structure regarded as discrete entities, these parts being electrons and protons.

In the Bohr atom, on the other hand, considerable success has been achieved by uniting the principles of mechanics to a quantum-energy conception. The latter conception seems so far removed from the *continuous* characteristic which dominates all purely mechanical motions, as understood in the kinematics of bodies, that one is inclined to regard the problem, as a connected whole, unsolved. Does the solution lie in a blending of geometry with physics? The answer seems to be in the affirmative, for Einstein's mode of analysing phenomena of certain kinds broadly involves this very idea, which has been indicated in the previous chapter.

The way out of this dilemma is possible in so far as a "construction" might be devised which would point the way. Suppose, therefore, we proceed to construct a highly artificial type of world in which well-known phenomena play a part, but that they are in many respects so exaggerated as to give the picture a more forceful aspect and bring into more connected evidence factors which may be overlooked in our present-world analysis owing to insufficient appreciation of something of real importance in the scheme.

The material world as we find it is largely conditioned by the conglomerate of chemical elements. If, for example, the earth were composed entirely of pure iron containing belts of pure copper, and it were devoid of any atmosphere, conditions might be such that electric currents circulating in this huge mass of metal would produce regions very highly magnetized; and assuming that we were able to explore such regions with devices as would be suggested to a physicist, then many small-scale phenomena, with which we are familiar in the laboratory, would be presented to the explorer on a much

bigger scale. Our gravitational experiments with masses of iron would be eclipsed by the more powerful magnetic attractions. There being no atmosphere, extreme conditions of temperature would occur due to the rays from a distant sun in one case, and in the other to the dark side of the metallic world becoming exceedingly cold in polar regions where the nights would be very long. These and other conditions might give rise to the circulation of large electric currents in the surface of this "earth." Passing over minor difficulties, there would be remarkable phenomena to study.* The very low night temperatures (bordering on the absolute zero) of bodies out of contact with the earth would afford most interesting experiments. A closed loop of suitable metal moved to and fro, so that its upper part would cut magnetic lines of force emanating from one of the magnetic polar regions, would be the seat of very powerful currents, as may be expected from Onne's laboratory experiments conducted at temperatures just above the absolute zero. A current established in the loop by its movement would continue to flow for hours or even much longer. A great many thousand amperes (C) might thus be caused to flow in the loop, as the temperature would be so low that no ohmic resistance (R) would be encountered and no heat generated in the conductor: there would be no C'R loss. Such a loop would resist being moved, and it would tend to slip out of one's grasp by its reaction with the earth's field, and if free it would then swing round into such a position as would make its own magnetic field coincide with that of the earth. During this movement its own current would fluctuate, and a magnetic wave, like a wireless wave, would be detectable a little distance away from it.

* The reader should realize that in constructing an artificial world of this kind certain difficulties are presented which have to be glossed over. It may, however, be assumed that the conditions were so adjusted as to give the general results indicated.

Here is a case of the original mechanical movement imparted to the loop appearing as a wave of radiation, but it may be assumed that the wave would have two characteristics; the first one due to the establishment of the current and the second due to the settling of the loop into the position so that its field would coincide with that of the earth. Now the wave pulses might be influenced by the massiveness of the loop, for with a given urge a thin-wire loop would not give rise to the same wave interval as in the case of a very massive loop, but there would always be a certain correspondence between the energy originally imparted to the loop by the application of muscular force and the radiation emitted for a given position with reference to the earth's polar surface. If now the experiment be carried out at different altitudes (levels), then there would be slightly different intervals corresponding with the levels, owing to the radial field.*

Thus it will be seen that we have produced a Bohr atom in so far as the energy radiated begins to assume a quantum-like characteristic. This earth-atom with the loops corresponding to electrons does not, however, explain why there are *stationary states*.

At this juncture the geometrician appears on the scene. He proceeds to express all the quantities so far involved in terms of lines of the right length together with their angular relations, and he shows how by the rules of geometry the behaviour of this loop system can be completely expressed mathematically, but he finds that, in taking the different altitudes in the different experiments, the "line" measurement taken coincides with the magnetic line, and he remarks that this length can have no

* See footnote on next page. The reader should note that these ideas of different "intervals," etc., are not to be interpreted literally, since the precise calculations of such effects involve factors not fully gone into here, the idea being to gloss over minor difficulties in developing broadly the scheme.

physical significance, for one element of this line does not differentiate itself from another; and, therefore, if the measurement means anything the radial line must be a wedge or a cone; that is to say, it must thicken in extending out radially from the earth if it is to have a physical meaning attached to it as in the case of the other measurements. It should be remarked that in these problems it is the *number* of lines cut that counts in the calculation. This, therefore, leads to the introduction of a natural unit in the field system, and then the physicist begins to see that if this is really so, his loop of definite size must either cut this wedge or not, so that, if it vibrates within the confines of this unit wedge, nothing happens.* This leads then to the steady (stationary) states within the confines of the wedge element—that is to say, no energy is then radiated although the loop may vibrate.

Thus it will be seen that by this imaginary picture geometry becomes really physical if applied properly, and when this is understood the quantum-energy principle and the “steady” or “stationary” states may, in a measure, be elucidated.

A note of caution should be given here. It is not suggested that the above picture can be reduced to atomic dimensions and represent in any way the precise process of radiation as far as indicated, though the “natural unit” may correspond in some way by analogy to Planck’s h (see page 47). It is merely intended as a sort of simile to show that it is perhaps important to look to geometry, as developed by Einstein, as a solution of the riddle of the atom.

* The magnetic lines may be imagined to be radial like the spokes of a wheel, but each spoke would have a longitudinal cross-section corresponding to that of a wedge. Whether the transverse cross-section of this hypothetical element line would be hexagonal, round, elliptical, or some other analogous shape, is not considered here, as the case is one intended to illustrate a general principle, and it may not be physically true.

SUMMARY

Considering physics and geometry, from the point of view of these studies, to be fundamentally inter-related, more use should be made of these sciences jointly in elucidating certain phenomena. In short, space-physics is important. It is suggested in the case of the Bohr atom, involving quantum energy and stationary states, that a model might be constructed which will show with greater force the process of action in principle; but when the analogous model, as constructed here, is considered geometrically, a radial magnetic line becomes a cone or wedge, thus introducing a new factor in the calculation; and by the definition of energy, as developed by the reaction or interaction of a current and the lines of magnetism (involving the principle of the generation of n E.M.F. by cutting n lines per unit of time),* as the wedge widens, more lines would *not* be cut in a complete circle, and consequently a vibrating conductor moving within the confines of a single-wedge element would not generate energy that would be emitted as radiation. Thus a steady or stationary state is represented. These ideas seem to be in harmony with Einstein's developments in his theory of relativity, and this may be helpful in solving the riddle of the atom. In the model constructed, though it is on a large scale, it is not suggested that it would afford direct evidence of such "wedge" lines; but the smallness of the atom might lead to some proper analogous condition. The reader, upon giving these matters thought, will observe that the large-scale model militates against having wedge elements of the proportion (width) required to get appreciable results, for the lines are practically parallel to one another in a *large* world; but in a *small* world, such as the atom, this difficulty dis-

* The fundamental conception of energy along these lines is developed in Chapter XI.

appears. This defect in the large model could be overcome by making the experiments on a very large scale ; for the explorer would then be able to reach levels represented by a distance from the surface of the world equal to, say, its diameter ; but the better plan is to transfer the conception to the atom, since its field domain is of the right proportion relative to the size of its nucleus, or rather its nucleus is sufficiently small ; and, consequently, the wedge element would be relatively larger ; that is to say, compared with the movement of the electron its angular size would be appreciable. This conception implies that the electron vibrates rather than revolves, but it is to be noted that it is, as stated above, one of analogy, and it should not be pressed too far.

CHAPTER X

RADIATION AND ENERGY: PLANCK'S LAW OF RADIATION

IN this short chapter a brief account of the characteristic features of radiation is outlined, more particularly from the energy standpoint.

We are all more or less familiar with the spreading out or sorting out of different wave lengths by means of a prism. To illustrate exploring such a spectrum in order to determine its energy at different parts, a blackened platinum wire may be laid cross-wise in the spectrum band, and the heat that the wire absorbs (energy) indicated by noting the change in its electrical resistance. Traversing the spectrum by such a wire would then give values which could be used in plotting a curve *W* as shown in Fig. 2. The smallness of the energy on each side of the middle part led Planck to introduce the quantum idea and to devise a radiation formula based partly upon or related to the work of Lummer, Pringsheim, Wien, Lord Rayleigh, and others, which is—

$$K_{\nu} = \frac{h\nu^3}{c^2} \times \frac{1}{\frac{h\nu}{e^{hT} - 1}}$$

when K_{ν} = intensity

ν = frequency

h = Planck's constant 6.548×10^{-27} [erg. sec.].

h = constant = 1.346×10^{-16} [erg./deg.],

c = velocity of light in empty space.

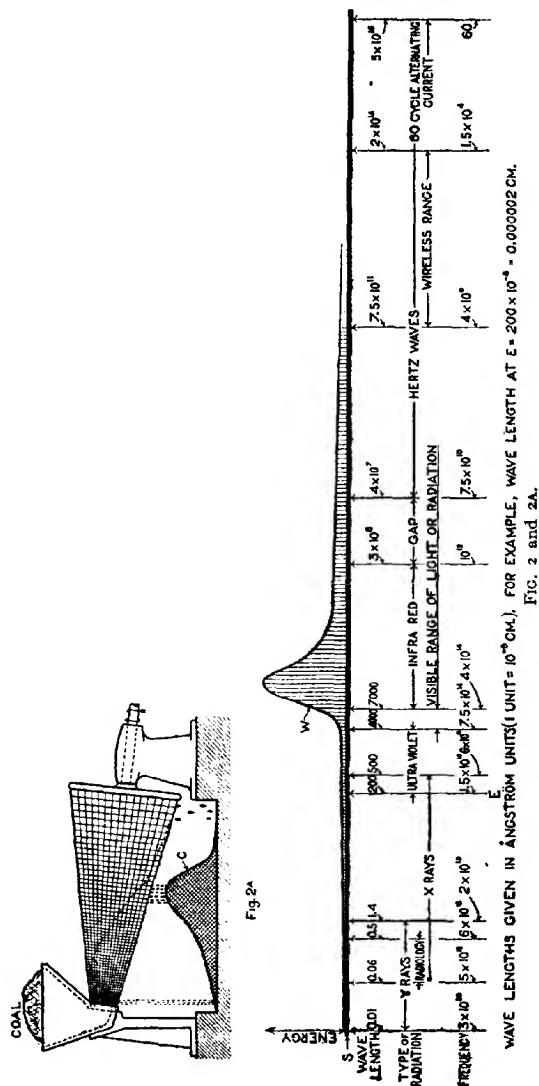
T = temperature.

e = base of Napierian logarithms (about 2.72).

(See "The Quantum Theory," by F. Reiche, translated by H. S. Hatfield and H. L. Brose.)

This famous formula involves the conception of an element of energy E , so that $E = h\nu$, and the constant h is of the nature of energy \times time, all of which will be made more evident from what follows.

In Fig. 2 is shown a complete spectrum, which extends each way towards infinity. The demarcation values given below the thick horizontal line S are those taken from a somewhat similar scheme in Dr. Kaye's book, "Practical Applications of X-rays," page 3. Fig. 2A is intended to illustrate by a mechanical distribution of pulverized coal, resulting in a pile C, the distribution of energy in the spectrum shown by curve W. Models of this kind have their limitations, but it will be seen that the coal can be regarded as distributed in *quanta*, illustrated by the size of the falling group-particles of coal. Similarly, in the case of radiation it is analysable in terms of energy units (erg-seconds; see Chapter VI) given out in bundles or group-quanta, according to the above idea of Max Planck, which formulates the curve W, and which, moreover, seems to imply that a thinned-out distribution of large quanta (high frequency radiation) describes the spectrum (S) on the left, while a thick feed of medium-sized quanta describes the middle, followed by much smaller quanta, but these are densely emitted, and they are of a low-frequency character as indicated. In Fig. 2A, the falling coal is only drawn at intervals so as to show more clearly the three extremes. It is to be noted that the front end of the rotating sieve may be so fine as to pass very little coal, but at the middle part, the mesh being much coarser, a relatively



large quantity passes per unit of time, and so leaves very little coal to pass through the tail part of the sieve.

It is important to note that to make the statement above read in a straightforward manner with respect to curve W, the model of Fig. 2A has to be turned round. When this is done the two curves agree better in their characteristic shapes, but of course they are only diagrammatic representations.

Another point is brought out by this model. The high-frequency distribution mechanically follows that which is of lower frequency; in other words, to produce high-frequency light by ordinary means it is necessary to produce heat first. Therefore, to produce light without heat it would seem necessary to work through the heat gamut of radiations, and to re-absorb the latter in some way internally and re-emit them as high-frequency light. Furthermore, by reducing the supply of coal the low-frequency waves, as in wireless, would only be produced. It is impossible by this model to curtail the coal supply and get high-frequency waves. The only way to accomplish this would be to introduce the coal at the big end of the sieve, but this would not be a natural procedure with such a model, and the simplicity of the scheme would be lost. The model therefore serves a threefold purpose, as is evident.

SUMMARY

According to Planck's theory and its illustration by means of a model, the energy of radiation does not involve a continuous process, but it is emitted in quanta, as partly described in Chapter VI. When the frequency is very high the quantum is large, but there are few of them as shown. When the frequency is very low the quantum is small, and there are many of them, but the total relative amount,

i.e. their sum, is small. When, however, the frequency is of a medium value, the quantum is also of a medium magnitude, and there is a considerable number of them, which means that the energy then reaches a maximum, as shown by the curves in the diagrams. The model shows that heat must precede light in its production, but that Hertz waves can be produced without passing through the heat and light stages.

See Appendix V on page 163 for further information and notes.

CHAPTER XI

THE FUNDAMENTAL ASPECTS OF ENERGY FROM THE STANDPOINT OF ATOMIC PHYSICS

IN the last two chapters mention was made of certain energy conditions which play a part in the analysis of those atomic activities revealed particularly in the emission spectra of the elements, and it seems a fitting place here to discuss the problem of energy itself from a somewhat more fundamental standpoint than is usual in most text-books.

The subject of energy is always an interesting one, and a few early views of a purely philosophical character will, it is hoped, form a suitable introduction. Some apology is necessary in this connexion, for chemists and physicists do not attach importance to the early views, as expressed without a foundation of exact experiment to support them.

Quoting from L. Rougier's "Philosophy and the New Physics," translated by M. Masius, he records that "In the first place, there are ponderable bodies, endowed with mass, weight, and structure, the aggregate of which constitutes matter; in the second place there are imponderable forces, divested of inertia, weight, and structure, the [negative?] aggregate of which constitutes energy." Further, he says, according to the views of Robert Meyer (1842), "Nature presents two categories of agents between which experiment shows an insurmountable barrier to exist. The first category comprises agents having the properties of being ponderable and impenetrable :

these are forms of matter ; the second comprises agents lacking in these properties : these are forces called imponderables on account of the negative property which characterizes them. Forces are indestructible, variable, and imponderable objects."

Considering more definite ideas of energy, it is of course well known that *muscular exertion* illustrates one of the most primitive conceptions of this idea, but this is obscured by physiological processes of a kind not fully understood. Mechanics has, however, given expression to very definite ideas respecting energy, and the quantitative evaluations will be considered by way of further introduction to the most recent views of the subject.

The definition of energy seems best stated in connexion with the conditions under which it, as an idea, is perceived. For instance, we may say : *the energy of a moving body*, meaning that the energy is considered from the position of "rest" relative to the body. The moving body would do work or act destructively, when striking another body, according as the latter is relatively at rest. *Relatively at rest* is obviously a *relative* statement meaning that the energy of A relative to B is governed by the relative velocities a , b , taken in the sense just indicated.

The reader might here inquire—taking relative movements as a criterion for relative energy, which could be realizable by collision—what is the greatest amount of this relative energy possible in bodies ? The greatest known velocity is that of the propagation of light or electromagnetic waves in a vacuum, which is 299,860 kilometres per second. Electrons (as β rays) are shot off from radium C at a velocity of about $\frac{1}{10}$ ths that of light (see Table VII, page 96). A body moving with the limiting velocity of light would probably represent the greatest amount of energy when taken in its most concentrated form—i.e. its energy density would be greatest ; and in

evaluating the energy it would be proportional to this velocity v squared and multiplied by the mass of the body m , or $\frac{1}{2}v^2m$ when considered on the basis of the classical mechanics. It is important to note that this energy by itself means nothing, for, so long as there is nothing interposed to arrest or retard the movement of the body, the energy is an indeterminate factor.* To start the body from rest and raise it to a given velocity (i.e. relative to its rest velocity) is a different matter, for energy has to be expended to a definite amount to effect the movement. To bring an ordinary piece of matter to a velocity just short of that of light would require a concentration of energy greater than is possible by known means at our disposal.

Thus it will be seen how energy is dependent upon conditions, and its appreciation rests upon the relative velocities involved, which may vary from zero to that of light, but with exceedingly high velocities, near to that of light, only the electron can partake of that velocity.

When, as already intimated, energy is regarded from the *cause* side of motion, so to speak, we have to consider the *work* performed in producing the motion (it may be transferred to the moving body), and in the classical mechanics work is *force* (f) operating through a *distance* (d). $Work = fd$. Now when this work is performed energy is involved, so that $fd = \frac{1}{2}mv^2$, which is the expression for kinetic or motion energy of a body. The energy may be potential or stored up, as when the force raises a body from the floor to a given level and it is held at this level. When it is released the energy is returned in the form of a blow when the body strikes the floor.

* Consider our planetary system drifting in space. How are we to say what energy a body moving on our planet might evolve in conflict with some other body also drifting in space? The energy is thus indeterminate.

90 THE CHEMICAL ELEMENTS

There are many forms of energy, for example—

1. *Motional*, which may be rectilinear, rotational, vibrational, as mechanically distinct from
2. *Electrical*, as when electrons are set in organized motion, including magnetic phenomena, and
3. *Chemical*, when atoms combine to form compounds.

Returning now to the high velocities mentioned above, a correction has to be applied when the velocities approach that of light propagation; for, according to the theory of relativity, the mass then becomes greater, and as a matter of fact it would become infinitely great at the exact velocity of light even in the case of the electron, but this "relativity" mass is a relative one, for if an observer moved with the electron at this prodigious velocity—assuming for the sake of argument that this were possible—he would not then discern in the electron any phenomena to reveal this infinite mass, whereas a relatively stationary observer would, when measuring the motion, discover this increase of mass as the velocity of light was attained. While this analysis is important from the standpoint of exact fundamental measurement, it need not be gone into here. The above elementary treatment will not satisfy the student wishing to follow the subject in its latest relativity development. To meet this demand would be impossible here, but the following footnote from Eddington's "Mathematical Theory of Relativity" will show what has been accomplished in this direction.*

* "Energy.—When the units are such that $c = 1$, we have

$$M = m(1 - v^2)^{-\frac{1}{2}} \quad [c = \text{velocity of light}]$$

$$= m + \frac{1}{2}mv^2 \quad (a)$$

if the speed is small compared with the velocity of light. The second term is the kinetic energy, so that the change of mass is the same as the change of energy, when the velocity alters. This suggests the identification of mass with energy. It may be recalled that in mechanics the total energy of a system is left vague to the extent of an arbitrary additive constant, since only changes of energy are

Now returning to the above examples of several kinds of energy, there is a little table of different types given in an early book, "Dictionary of Science"

defined. In identifying energy with mass we fix the additive constant m for each body, and m may be regarded as the internal energy of constitution of the body.

"The approximation used in (a) does not invalidate the argument. Consider two ideal billiard balls colliding. The conservation of mass (relative mass) states that

$$\Sigma m(1 - v^2)^{-\frac{1}{2}} \text{ is unaltered.}$$

"The conservation of energy states that

$$\Sigma m(1 + \frac{1}{2}v^2) \text{ is unaltered.}$$

But if both statements were exactly true we should have two equations determining unique values of the speeds of the two balls; so that these speeds could not be altered by the collision. The two laws are not independent, but one is an approximation to the other. The first is the accurate law, since it is independent of the space-time frame of reference. Accordingly the expression $\frac{1}{2}mv^2$ for the kinetic energy in elementary mechanics is only an approximation in which terms v^4 , etc., are neglected.

"When the units of length and time are not restricted by the condition $c = 1$, the relation between mass M and energy E is

$$M = E/c^2 \quad (b)$$

Thus the energy corresponding to a gram is 9×10^{10} ergs. This does not affect the identity of mass and energy—that both are measures of the same world-condition. A world-condition can be examined by different kinds of experimental tests, and the units gram and erg are associated with different tests of the mass-energy condition. But when once the measure has been made it is of no consequence to us which of the experimental methods was chosen, and grams or ergs can be used indiscriminately as the unit of mass. In fact, measures made by energy-tests and by mass-tests are convertible like measures made with a yard-rule and a metre-rule.

"The principle of conservation of mass has thus become merged in the principle of conservation of energy. But there is another independent phenomenon which perhaps corresponds more nearly to the original idea of Lavoisier when he enunciated the law of conservation of matter. I refer to the permanence of *invariant mass* attributed to our ideal billiard balls but not supposed to be a general property of matter. The conservation of m is an accidental property like rigidity; the conservation of M is an invariable law of nature.

"When radiant heat falls on a billiard ball so that its temperature rises, the increased energy of motion of the molecules causes an increase of mass M . The invariant mass m also increases, since it is equal to M for a body at rest. There is no violation of the conservation of M , because the radiant heat has mass M , which it transfers to the ball; but we shall show later that the electromagnetic

2 THE CHEMICAL ELEMENTS

.873), edited by G. F. Rodwell, which is worth reproducing here, viz. :—

Classification.	Kinetic.	Potential.
Visible energy.	Due to visible motion.	Due to position or advantage.
Molecular energy	Electricity. Due to electricity in motion.	Due to electrical separation or opposite electrical states.
	Heat. Radiant heat and light, absorbed heat.	Potential energy of absorbed heat.
	Chemical action. Due to actual chemical action.	Due to chemical arrangement.

Considering now the unit of energy, the *erg*, it may become the unit of work as well, for it is a unit of force acting through a distance of one unit of length which is a *centimetre*.

When considering the forces at play in the atomic mechanism, as already discussed, it is evident that electrical phenomena are here involved for *two* reasons, viz. :—

1. Because the waves made by means of a Hertz apparatus, or in modern terminology, a wireless generating set, are the same in character as those of light, except that they are of much longer wave

length. They have no invariant mass, and the addition to *m* is created out of nothing. Thus invariant mass is not conserved in general.

"To some extent we can avoid this failure by taking the microscopic point of view. The billiard ball can be analysed into a very large number of constituents—electrons and protons—each of which is believed to preserve the same invariant mass for life. But the invariant mass of the billiard ball is not exactly equal to the sum of the invariant masses of its constituents. This is because the invariant mass of each electron is its relative mass referred to axes moving with it; the invariant mass of the billiard ball is the relative mass referred to axes at rest in the billiard ball as a whole. The permanence and permanent similarity of all electrons seems to be the modern equivalent of Lavoisier's 'conservation of matter.' . . . see page 116 of this book.]

"It will thus be seen that, although in the special problems considered the quantity *m* is usually supposed to be permanent, its conservation belongs to an altogether different order of ideas from the universal conservation of *M*."

length. The atomic mechanism gives rise to this type of radiant energy.

2. Because all the knowledge gained of the atom from the ultimate energy point of view is, in short, largely an accumulation of electrical data (see next chapter).

It is reasonable, therefore, to consider the definition of energy in purely electric terms and on a scale commensurate with that of the atomic edifice if it is considered desirable from a fundamental point of view to work back to the origins of things in their smallest terms—their least common multiple, as it were.

This may mean that the revolving or vibrating electron displacement gives rise to the emission of energy which is equivalent to a current in a wire being moved through a magnetic field so as to produce an electromagnetic wave whereby the energy can be defined in terms of a displacement current in the Maxwellian sense.

The atomic domain is a centralized structure as in the Rutherford atom, with its concentrated nucleus, in which practically all the mass resides, while in the Bohr atom involving this structure the electrons comport themselves in changing orbits, when radiation is emitted or absorbed, according to quantum formulæ. The energy unit in this case is 6.55×10^{-27} . This may be regarded as an electromagnetic unit expressed in terms of mechanical ergs. This exceedingly small fraction of an erg of necessity must involve something else which has reached a limit of smallness; and this, it may be assumed, is the line of force cut by the electron, using the current-in-a-wire analogy.

It is unfortunate to have to break off here the discussion of this interesting problem, but it is hoped that the reader will have formed a sort of mental picture of the processes, whilst realizing that much is presented by way of analogy rather than as cut-and-dried fact.

SUMMARY

Starting with certain purely philosophical notions, it is clear that matter and all that is not matter form the energy-material universe, and that the energy does not necessarily reside entirely within matter ; but when the smallest energy unit in a system of energy based upon the atom is considered, it becomes by analogy limited by the centralized state of the atom involving lines of force. This energy passes out as radiation which is of an electromagnetic wave type, and this leads back to the fundamental unit of energy being by analogy expressible in terms of lines of force cut by a revolving electron, the revolving electron in turn simulating a current in a wire, so that a sort of reactionary wave is sent out radially from the atomic mechanism acting as a generating station, as in a wireless system. It has been stated that the knowledge of the atom is, from the energy point of view, an accumulation of electrical data. This seems a rather bold statement, but it will be made more evident in the next chapter.

CHAPTER XII

THE ELECTRICAL NATURE OF THE ATOM AS REVEALED BY RADIO-ACTIVITY, AND THE CLASSIFICATION OF THE RADIO-ISOTOPES

FROM the preceding chapter it may be assumed that evidence is accumulating to the effect that the atom is by analogy an electrical system similar in some respects to a wireless broadcasting station. Approaching the subject through the channels of radio-activity leads to precisely the same general view. Convergent experimental work point to the atom as one of the most interesting mechanisms the physicist and the chemist have had to study and that it is essentially electrical.

The gradual breaking down of the radio-elements is a phenomenon which can be explored with great effectiveness and accuracy, for the electrical behaviour of the successive products, starting with uranium and finishing at lead, afford, with the aid of the modern electroscope, etc., means of analysing these radio-changes.

It will be assumed that the reader is familiar with the general principles of radio-active phenomena; but as this book would hardly be complete without a table which shows in a systematic way much that is known about these elements, one is here given (Table VIII), together with a supplementary scheme (Table IX), showing certain numerical regularities in connexion with these problems of atomic structure and the quantitative production of some of the elements.

10	83	Radium C	RaC	214	19.5 m.	28.1 m.	5.92×10^{-4}	99.97% β and γ	{ .786; .862; .949; } - .957 - .0641 - .33; .39 - .5500 - .43.3 - .3.58 - ? - .	- .13.2; 53 - . - . - . - . - . - . - .	.115 - . - . 45; .99 585 - . - . - . - .	.59 - . - . - . - . - . - . - .	
11	82	Radium C'	RaC'	214	10 ⁻⁴ s.	10 ⁻⁴ s.	10^{-4}	α	- .957	- .	- .	- .	- .
12	84	Radium D	RaD	210	16.5 y.	23.8 y.	1.33×10^{-4}	(β and γ)	- .0641	- .	- .	- .	- .
13	83	Radium E	RaE	210	5.0 d.	7.2 d.	1.01×10^{-4}	β	- .33; .39	- .	- .	- .	- .
14	84	Radium F	RaF	210	136 d.	196 d.	5.90×10^{-4}	$\alpha(\gamma)$	- .0523	- .	- .	- .	- .
15	82	Radium G	RaG	206	- .	- .	- .	- .	- .	- .	- .	- .	- .
16	83	Radium C	RaC	214	- .	- .	1.8×10^{-4}	$\alpha(\gamma)$	- .	- .	- .	- .	- .
17	81	Radium C'	RaC'	214	- .	- .	8.3×10^{-4}	β	- .	- .	- .	- .	- .
18	82	Radium G	RaG	210	1.4 m.	2.0 m.	- .	- .	- .	- .	- .	- .	- .

Note.—There is a branching at RaC (10) which links up this lower series (17, 18). See Table VIII on page 107.

ACTINIUM SERIES

19	92	Uranium ?	U	?	- .	- .	- .	α	- .	- .	- .	- .	- .
20	90	Uranium Y	UY	?	1.04 d.	1.5 d.	7.8×10^{-4}	β	- .	- .	- .	- .	- .
21	91	Protoactinium	Pa	?	1.2×10^6 y.	1.7×10^6 y.	1.9×10^{-4}	α	- .	- .	- .	- .	- .
22	89	Actinium	Ac	?	20 y.	28.8 y.	1.1×10^{-4}	$\alpha(\beta)$	- .	- .	- .	- .	- .
23	90	Radioactinium	RdAc	?	19.5 d.	28.1 d.	4.11×10^{-4}	$\alpha(\beta)$	α .0559; β .38; .43; .49	- .	- .	- .	- .
24	88	Actinium X	AcX	?	11.4 d.	16.4 d.	7.06×10^{-4}	α	- .0550	- .	- .	- .	- .
25	86	Actinon	An	?	3.9 s.	5.6 s.	.178	α	- .0600	- .	- .	- .	- .
26	84	Actinium A	AcA	?	2.0×10^{-4} s.	2.9×10^{-4} s.	345	α	- .0627	- .	- .	- .	- .
27	82	Actinium B	AcB	?	36.1 m.	52.1 m.	3.2×10^{-4}	(β and γ)	- .	- .	- .	- .	- .
28	83	Actinium C	AcC	?	2.15 m.	3.10 m.	5.37×10^{-4}	α	- .	- .	- .	- .	- .
29	81	Actinium C'	AcC'	?	4.71 m.	6.83 m.	2.44×10^{-4}	β and γ	- .0589	- .	- .	- .	- .
30	82	Actinium G	AcG	?	- .	- .	- .	- .	- .	- .	- .	- .	- .

There is probably a branching in this series. See Table VIII on page 107.

* .53; .60; .67; .73.

Before, however, presenting the periodic table above mentioned, a list of the radio-elements will be given together with much of the data experimentally discovered in this field of investigation. The information shown in Table VII is made complete for reference, being a somewhat close copy of the original "Report by the International Committee on the Chemical Elements," 1923, which has the endorsement of F. W. Aston, G. P. Baxter, B. Brauner, A. Debierne, A. Leduc, T. W. Richards, F. Soddy, and G. Urbain.

In the following notes much explanatory matter will be introduced by way of examples, but which apply generally throughout the above table.

NOTES

1. The average life-values given in Column G are designated by the letter θ , and in the case of uranium I

$$\theta = \frac{T}{\lambda} = 2440 \times 0.97 \times 3 \times 10^6 \times \frac{226}{238} \\ = 6.75 \times 10^9 \text{ years.}$$

In this equation 2440 is the average life of radium ; 0.97 is the branching coefficient ; and $3 \times 10^6 \times (226/238)$ is the ratio between the number of atoms of uranium and radium in equilibrium in minerals containing these elements. It is to be noted in this connexion that if the actinium series is independent of that of uranium I at the inception, λ cannot be calculated by this method (see Notes 19 and 21). The value of λ is obtained by the direct counting of α particles from a uranium compound, and it is 4.57×10^{-18} from which $\theta = 7 \times 10^9$ years ; and the *half period* (see Column F), indicated by the letter T, is 4.8×10^9 years. T is the *period*, i.e. the time in which the quantity of the radio-element

is diminished to one half: $\lambda T = -\log 0.5 = 0.69315$ and $\theta = 1.443T$. In making some of the calculations according to the relations given, the years, to take an example, must obviously be reduced to seconds (see Note 6), i.e. the time quantities must be reduced to a common unit.

2. Uranium X_1 . It will be seen that the *absorption coefficient* for the β radiation from this radio-element is 463 in terms of aluminium thickness, thus: ^{238}Al , which in this case is $1/463$ cm., or $\mu(\text{cms.})^{-1}$. See next Note.

3. Uranium X_2 . This element is also called brevium. Referring to Columns L, M, N, there are three types of absorption shown. Quoting from the Report (*loc. cit.*) ^{238}Al is the *absorption coefficient* of the β rays in aluminium, the thickness being in cm.^{-1} measure. ^{238}Al and ^{238}Pb are the absorption coefficients of the γ -rays in aluminium and lead respectively, the thickness being measured in cm.^{-1} ; the latter is only given for the most penetrating γ -rays. If I_0 is the initial intensity and I the intensity after the rays have traversed x cm. of the absorbent:

$$I = I_0 e^{-\mu x} \quad \log_{10} I_0/I = 0.4343\mu x.$$

If D is the thickness corresponding to the absorption of one half of the rays: $^{238}D = 0.693$. See Note 2.

4. Uranium II. The a_0 value in this case is 2.75, which is the range in cms. of the α rays at 0°C. and at a pressure (p) of 760 mm. of mercury. The range formula at t° under p mm. of mercury is—

$$a = \frac{a_0(273 + t)760}{273p}$$

t being the temperature taken on the centigrade scale.

5. Ionium. As an example of the velocities of the α rays emitted, the value V is 0.0485 relative to that of light, taking the velocity of light at 3×10^{10} cms. per second in a vacuum. The actual velocity

in this case is $0.0485 \times 3 \times 10^{10}$ cms. per second.
For α rays $V = 0.0342a^{\frac{1}{2}}$. For example—

$$0.0342 \times 2.85^{\frac{1}{2}} = 0.0485.$$

6. Radium. The *radio-active constant* of the *equation of transformation* in the case of radium is 1.30×10^{-11} . The following from the Report (*loc. cit.*) is of general interest in this connexion. $\lambda(\text{sec.})^{-1}$ is the *radio-active constant* of the *equation of transformation*.

$$dQ = -\lambda Q dt, \quad Q = Q_0 e^{-\lambda t}, \quad \log_{10} Q_0/Q = 0.4343 \lambda t$$

in which Q_0 is the initial quantity and Q the quantity remaining after time t (seconds).

$\lambda = \frac{dQ}{Q} \frac{1}{dt}$ represents the fraction of the element

transformed, reduced to the unit of time.

7. Radon, or radium emanation (RaEm), or niton (Nt) are the names given to this radio-element, it being an inert gas. It is often referred to as an *inactive* gas, but the word *inert* is better, because some writers now use the word *inactive* to describe all the elements which are not radio-active. The several names are provisional like the others of the above table, which in time will be revised, a complete new nomenclature being required.

8. Radium A. This element is a solid like all the others, except radon and its isotopes, actinon and thoron given below.

9. Radium B. It will be noted that the β rays are emitted by this element with five ranges of velocity relative to that of light.

10. Radium C. This member undergoes a double disintegration. 99.97 per cent. of the atoms emit β rays—producing the radio-element RaC', which emits α rays—and 0.03 per cent. of the atoms emit α rays, producing the radio-element RaC'', which emits β rays.

11. Radium C'. Referring to the radio-active constant (10^6), this value has been indirectly deduced, from the range of the α rays. This is a very short-lived radio-element.

12. Radium D. This radio-element is also known as radio-lead, being isotopic with ordinary lead; or isotopic with the end-members of the series indicated by the letter Ω , which are also isotopic with ordinary lead. The radio-isotopes are shown fully in Table VIII, on page 107.

13. Radium E.

14. Radium F. This radio-element is also known as polonium (Po).

15. Radium Ω' . This element is also known under the following descriptions: radium G, radium end, or simply "end." It has no known radio-activity, and it appears to be the stable end-product of change, which product is like ordinary lead, except that its atomic weight is about 206 by calculation. This member of the series, though not radio-active, is classed as a radio-element.

16. Radium C. This radio-element may be regarded as a part of RaC, but being differentiated from it by giving effect to a branch member RaC". This double disintegration is shown more clearly in Table VIII on page 107.

17. Radium C". This radio-element is the first isolated branch member of this short branch series; it is also known as radium C_2 (RaC₂). See Table VIII.

18. Radium Ω'' . This is another end-member which bears designations like those relevant given in Note 15. In the Report it is marked "hypothetical." It appears to be like lead in practically every way except that its atomic weight should be 210 by calculation.

19. Uranium is here shown because it is, or it contains, a head member of the actinium series. Uranium Y is the first supposed member of the actinium series. UY may be derived from UI or UII. In

this case 3 per cent. of the atoms of uranium produce the actinium family, while 97 per cent. produce the radium family. It has been suggested that UY arises not from UI or UII, but that the actinium series may have its origin in a *third* isotope of uranium for which the name "actinouranium" has been proposed. For purposes of reference in Table VIII this hypothetical radio-element will be symbolized by the letters AcU.

20. Uranium Y. See Note 19.

21. Protoactinium. This radio-element is isotopic with UX₁, and being in the same group as tantalum, it has been designated eka-tantalum. It is of interest here to note that a new radio-element, uranium Z, has been discovered (O. Hahn, *Berichte*, 1921, 54 (B) page 1131). Its period is from 6 to 7 hours; it emits a β radiation, for which D_A varies from 0.0014 to 0.012; its parent is isotopic with thorium, but it cannot as yet be located in the series. See Notes 1 and 19.

22. Actinium. This radio-element appears to have no radiation of any kind, yet it changes into radioactinium according to the data obtained and here recorded. See Note 32.

23. Radio-actinium. This radio-element seems in a sense to make up for the inactivity of actinium in respect of rays, for in this case there is quite a variety in terms of velocity ratios, as given in Column J.

24. Actinium X. This radio-element is of course like radium, being isotopic with it. See Table VIII, where all the isotopic elements of the radio-elements are given.

25. Actinon. This is, as is well known, an inert gas, which has been called actinium emanation for many years, actinon being the new name.

26. Actinium A. This radio-element is of very transitory existence, having an average life of only 2.9×10^{-3} second. The other two very short-lived

members are radium C' and thorium C', the life of the latter being only 10^{-11} second: these "existences" are almost too short to give the element an existence at all.

27. Actinium B.

28. Actinium C. 0.2 per cent. of the α rays emitted by this radio-element have a range $a_0 = 6.10$, instead of 5.12. From this observation it has been concluded that 0.2 per cent. of the atoms undergo a transformation by the emission of β rays, as is the case in principle in respect of the radium C and thorium C branches (see E. Marsden and P. B. Perkins, *Phil. Mag.*, 1914, 27, page 690; R. W. Varder and E. Marsden, 28, page 818); but confirmatory evidence is desirable. See Table VIII where this branch is introduced, it being in harmony with the others.

29. Actinium C". This radio-element is also called actinium D.

30. Actinium Ω ". This is an end-member, also known as actinium E; or as actinium end; or simply as "end." It is isotopic with lead.

31. Thorium. The value given for λ is that obtained from the direct counting of the α particles emitted by a compound of thorium. All the other values are less; the smallest being 0.55 of that given in the table, and giving for $\theta = 3.45 \times 10^{10}$ years, and for $T = 2.37 \times 10^{10}$ years (L. Meitner, *Phys. Zeit.*, 1918, 19, page 257).

32. Mesothorium 1. This radio-element appears not to give out a radiation of any kind whatever, yet it changes into mesothorium 2, as indicated in the table. β radiation probably too feeble to detect.

33. Mesothorium 2.

34. Radiothorium.

35. Thorium X.

36. Thoron. This is the new name that has been suggested to take the place of the older and more clumsy one of *thorium emanation*. This radio-element is a gas and inert, like radon and actinon.

37. Thorium A. This is a short-lived radio-element, its average life being 0.20 second.

38. Thorium B.

39. Thorium C. This radio-element undergoes double disintegration. 65 per cent. of its atoms emit β rays and produce the radio-element ThC', which gives off α rays. 35 per cent. of the atoms of ThC, on the other hand, emit α rays and produce the radio-element ThC'', which in turn gives off β rays. Double transformation value Column H is 1.25×10^{-4} .

40. Thorium C'. See Note 39.

41. Thorium Ω' . This is another end-member which has been designated thorium D; or thorium end; or simply "end." Its atomic weight is close to the value 208, if not exactly this value.

42. Thorium C (see Note 16). For this radio-element the value of $a_0 = 4.69(?)$, which is that corresponding with $V = 0.0572$ as directly measured. There is another value for a_0 viz.: 4.55 as measured, but not shown in the above table.

43. Thorium C''. This radio-element has been known under the name of thorium D. See Note 39.

44. Thorium Ω'' . This is another end-member which has been designated thorium E; or thorium end; or simply "end." It is isotopic with lead.

45 and 46. Potassium and rubidium are somewhat of a puzzle, as, while they are radio-active, no products seem to accumulate which should show some chemical difference as in the proper radio-atom cases. The radio-activity may be due to an impurity which is radio-active. There are missing members of the halogen group (VII) and *one* of Group I, and these might exist in exceedingly minute quantities, and their behaviour might be different from that common to the other radio-active members. These existing as an impurity in the above stable elements of Group I might account for this abnormal phenomenon, but this is pure speculation by the present

writer. These remarks are intended to show that K and Rb need not be considered as truly radio-active.

Passing now to Table VIII, which shows the scheme of change better than the above table, it is to be noted that it contains the radio-elements as an *addition* to the periodic table shown on page 34, but only the lower part of the latter table is here given.

NOTES :—Prof. Soddy—Royal Institution discourse, May 4th, 1923—said that the actinium family had its origin *either* in UI or UII, for it was impossible to decide which, as the intervening products UX₁ and UX₂ are too short-lived to enable a separation of UI from UII to be effected, these being obviously isotopes. The actinium family is productively a weak branch, representing only 3 per cent. relative to the main origin of 97 per cent.

In this table it will be seen that to bring the two sides of the table into connexion it may be considered as wrapped round a cylinder so that the inert gases on the left will be superposed on those carried forward on the right.

It will be seen that the sloping arrows represent the α -ray changes, while the other arrows represent the β -ray changes in practically all cases. It is to be noted that as the element gains or loses electricity so it changes its type. The β rays are negative electrons and the α rays are doubly charged helium atoms, the double charge being that which would arise from a neutral atom losing two electrons. These systematic changes in the atom concur with systematic changes in its type, and this is fully revealed by the tabular scheme shown. In order to indicate the radio-active process of disintegration in more detail it is necessary to make the atomic-number places (from 86 to 92 left; 81 to 85 right) very deep, but since all the radio-elements that fall in each place are isotopic it is equivalent to filling

107

TABLE VIII

Diagram illustrating the selection of C, S, and T elements for characterizing the AT-NO. PLACES, and the resulting ATOMIC NO. PLACES, and the resulting ATOMIC NO. PLACES.

C = ELEMENT SELECTED TO CHARACTERISE THE AT-NO. PLACES.
S = SPECIAL NUMBERS ASSIGNED TO ATOMIC-NO. PLACES.
T = END MEMBERS: SEE NOTES NOS. 12, 18, 19, 30, 41, 44.
THE VERY SHORT-LIVED RADIO-ELEMENTS ARE:-

ATOMIC NO. PLACES:

AT-NO. PLACES	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																							
Element	Xe	Cs	Ba	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Ta	W	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn	Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Mn	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr	Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe	Cs	Ba	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Ta	W	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn	Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Mn	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr	Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe	Cs	Ba	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Ta	W	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn	Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Mn	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr	Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe	Cs	Ba	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Ta	W	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn	Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Mn	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr	Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe	Cs	Ba	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Ta	W	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn	Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Mn	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr	Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe	Cs	Ba	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Ta	W	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn	Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Mn	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr	Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe	Cs	Ba	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Ta	W	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn	Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Mn	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr	Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe	Cs	Ba	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Ta	W	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po

the places with isotopes, the greatest number occurring in the place represented by atomic number 82.

It will be remembered that in Chapters III, IV, and V an argument was presented in support of the idea that there were atomic-number places falling in a regular sequence, in which the quantitative production of the elements reached a minimum value. Similarly, in the case of the radio-elements there are places of maximum and minimum production suggesting that the atomic number may form a basis for arriving at the stability of the atomic complex. This idea is not at variance with the electrical nature of the atom, as it is known that certain combinations of magnets are possible while others are not possible; but no systematic atomic structure has been built up on these lines, though various attempts have been made with partial success. This failure is to be expected, because it is difficult to arrange the magnets in a three-dimensional pattern—that is to say, floating magnets give certain suggestive configurations; but to make the experiment more complete the magnets should be free to take up all positions of equilibrium within a sphere, and this arrangement is not possible with magnets having N and S poles, even though the suspension were such as to admit of any three-dimensional configuration.

Whether these quantitative relations be considered from the point of view of maximum or of minimum productions, the fact remains that there are stable states which seem to be connected with productiveness, and unstable states connected with non-productiveness; and the patterns of stability, as they may be termed, can be simulated to some extent to those obtained by experiments involving the use of floating magnets.

The foregoing problem can therefore be approached in two ways, viz.: (1) experimentally by using magnets or by similar device, (2) mathematically by studying the construction of numbers, in par-

STABILITY AND PRODUCTIVENESS 109

ticular atomic numbers. Attempts in the latter direction have already been given in the chapters above cited. A further study of numbers is of interest in connexion with the radio-isotopes, and this will now be touched upon briefly, as it is believed that it will become of importance *in principle* when more knowledge can be brought to bear upon the problems. A start may be made even though obviously an imperfect one.

The radio-active elements proper possess high atomic weights, and they occur at the end of the general series which seems to suggest that their instability arises from an auxiliary structure of the atom which is built on to the more normal stable structure. Considering now atomic-number places from thallium to uranium inclusive, these contain the radio-atoms; and their numbers in each place or compartment are a sort of index of stability and productiveness, as, when the number is greatest, the stability tends to reach a maximum in most cases. The number of radio-elements per atomic-number place may therefore be taken as a stability factor—at least for the purpose of a first approximation.

In order to illustrate this idea, let it be assumed that the atom is a cellular structure something like an orange. Now referring to Table VI, on page 34, it will be seen that in several of the wedge series "17" becomes a limiting number. Pressing this "limit-number" idea further, values *S* may be assigned to certain atomic-number places as shown in Table VIII. These numbers may be regarded as trial sets to be put to a test of usefulness.

If the atomic number of each place is more or less made up of these sets (*S*), so that in the case of atomic-number place 85 there are 5 sets of 17 each, this gives the number 85 without a remainder over in this example.

In keeping with the trend of this reasoning is the idea that the difference between the atomic

ever, serves to illustrate with figures the *general idea of stability, instability, productiveness, and non-productiveness, as connected with the atomic numbers.*

SUMMARY

There is an accumulation of evidence that the atom is an electrical system. This system has been thoroughly studied in some respects, for in the case of the radio-active elements they emit positively-charged helium atoms and negative electrons in such a systematic manner that it has been possible to make a complete periodic classification of these elements. The electrical data and other data now known in connexion with these elements have been brought together in an extensive set of tables issued by the International Committee on Atomic Weights, and these are reproduced in this chapter (Table VII) with notes and explanatory statements. It is expected, however, that the reader will have consulted standard books on radio-activity, as it is impossible to appreciate fully the significance of the data here given without some grounding in the subject. Making use of some of the tabulated information and of the general scheme of classification, a special form of periodic table has been prepared which fits on to the main table shown on page 34. In the former table certain data are inserted, being based upon the idea that the atomic numbers may be analysed in connexion with another series of numbers already revealed in the above-mentioned main table. Another table is developed in order to show how these data can be provisionally arranged to give expression to the atom being stable or unstable, produced in quantity or not even produced at all; and this treatment is in general harmony with the ideas developed in Chapters III, IV, and V, viz., that the prolificness in production is dependent

112 THE CHEMICAL ELEMENTS

upon number. The latter part of this chapter may be designated a *study in numbers*, but this study is intended only to show the possibilities in this direction without offering a complete solution of this phase of the problem, i.e. of stability, etc. Whatever may be said for or against the ideas advanced, there is a general agreement between experiment and theory, but the reader is here cautioned not to expect too much of "theory" as there is a good deal of unexplored ground in this part of the atomic field.

CHAPTER XIII

MAGNITUDES AND RELATIONSHIPS

THE subject of *magnitudes* is a very large one, and it can be shaped so as to include almost anything connected with science. The main object in view here is to go over the ground already traversed in the previous chapters and to expand certain features which have a bearing on the general subjects under study. The treatment involves "magnitudes," so that this labelling will, it is hoped, be found sufficiently descriptive, especially in connexion with "relationships" which form the connecting links in these matters.

Beginning with the negative electron, it is often spoken of as a *body* having an intrinsic mass of $1/1840$ th that of the hydrogen atom, on which body resides a unit negative charge, this being the smallest negative entity thus far discovered. This definition, while correct in the main, involves a little more specification than experiment has yet revealed, for we do not know whether the electron has a *two-fold structure*, i.e. whether it is a *body* plus a *charge*. It may be a negative charge or atom of negative electricity and nothing more.

An analogy will illustrate this possibility. One would not specify an apple in terms of its core plus apple. The whole thing is an apple, and in the sense here intended the core is a hollow space. Similarly the electron may be a body-like charge with a hollow interior. It is a very small affair, however, being about 4×10^{-13} cm. in diameter. It

behaves in a vacuum tube as a body about 1840 times less massive than that of the atom of hydrogen, for it obeys influences which enable such a mass magnitude to be measured.

Considering now its associate, the proton (see Chapter I, page 16), here is another "body" actually smaller than the electron as regards bulk, since it appears to occupy a space which would correspond to that of an electron if the latter were compressed into about 1/1800th of its normal bulk. By analogy with the apple, it is like the seeds in the apple core in that they are smaller than the core proper, but, unlike the apple, the mass is 1840 times greater than that of the electron, which corresponds to the apple. What one possesses in *mass* the other possesses in *size*. Speaking *fundamentally*, mass is not thus proportional to size. In a *collective* sense, however, under suitable conditions, mass is proportional to size, in that one million atoms of a given kind have a mass of one, whereas, 100 million atoms of the same kind have a mass of 100, the unit being a relative and arbitrary term only. A distinction in magnitudes thus becomes evident.

The proton, like the electron, is a unit charge, but it is positive, and, as already stated, it exists as a more concentrated space entity than the electron; moreover, it is not known whether the positive electricity is something apart from something else so as to make it (the proton) a two-fold structure. It may be a one-fold structure which is a positive charge or atom of positive electricity and nothing more. See in this connexion Notes on Atomic Theory, page 16 of this book.

Like the electron, however, its charge may be its mass, and its centre, though inconceivably small, may be a core; but perhaps it is assuming too much to regard the electron as a one-fold structure.

The degree of smallness is of interest in itself, and whether we have reached the ultimate degree

of smallness in nature is not yet known. To say that there is something smaller than the core of the proton is to discuss a magnitude as yet unknown. Even to say that the proton has a hollow centre is speculation, except that we know that its charge (field) is an exterior affair to the proton taken as a point. It is sometimes spoken of as a point positive charge. The speculation in this case is not devoid of an experimental basis when the idea is comprehended in precisely the limited sense indicated. Limitations become necessary in these matters, as indicated in the next chapter.

From the above statements the hydrogen atom can be visualized, for it consists of 1 proton and 1 electron, the latter according to the Bohr theory revolving round the nucleus. Obviously the nucleus in this case is 1 proton.

The "revolution" here stated is *not* misleading, though in proportion as one body approaches another in mass they tend to revolve round each other, just as one would "twiddle" one's thumbs; but as the proton is so very massive compared with the electron, the latter revolves round a centre of gravity only slightly displaced, in fact they revolve round a common centre of gravity, for the nucleus is not absolutely stationary in the system. Elliptical revolution is not here considered, but the general principle indicated would remain the same in this case.

The electron considered in sufficiently close association with the proton would bring about a neutralization of the electrical field so that $+$ added to $- =$ zero. This perfect union may not be physically possible owing to the difference in the magnitudes involved, as will be seen by attempting to consider these two entities to have coalesced so that there will be no stray field. See page 57. There are two difficulties to be overcome to bring these entities into such close union as to eliminate all surrounding

field. One would be the activity in the Brownian-movement sense which might render the union impossible. The other would be the impossibility of making the point charge neutralize the much larger charge bulk of the electron.

Assuming, however, that perfect neutralization could be accomplished, then if the proton and the electron are one-fold entities they would be completely destroyed. Eddington in his "Mathematical Theory of Relativity," page 33, says: "It is still uncertain whether it [the conservation of matter] expresses a universal law of nature; and we are willing to contemplate the possibility that occasionally a positive and a negative electron may coalesce and annul each other. In that case the mass M would pass into the electromagnetic waves generated by the catastrophe, whereas the invariant mass m would disappear altogether." (See foot-note on page 90 of this book.) The view here presented seems to be against the realization of this possibility, but, of course, these are only views given more for the purpose of defining the proton and the electron. "Definition" in these matters takes the form of a discussion of possibilities, for by so doing we become familiar with the things discussed by the problems arising from the consideration of their characteristics.

The doctrine of neutrality, as it might be termed, is of interest since atoms which show the greatest neutrality in the free state, for instance, the inert gas atoms, are very far from being non-entities; in fact the neutral helium atom is a normal gas atom, and whenever neutralization appears to take place in molecular combinations no loss of mass is observed. Moreover, neutral compounds possess by addition certain ponderable characteristics of their atoms.

Thus it will be seen that this argument supports the two-fold theory of those entities known as protons and electrons, the ultimate particles composing matter,

but the one-fold theory may, nevertheless, be the true one.

How then is one to reconcile the one-fold theory with fact? The answer is perhaps an unexpected one. We cannot make a single measurement without a relative difference existing which may bring into being, so to speak, the very factors which on the one-fold theory might be destroyed.

Here we may take into consideration Einstein's relativity theory, for the basis of this theory involves of necessity nothing apparently existing if a differential measurement cannot be made or if it cannot be realized. All differential *measurements*, or perhaps one should say *effects*, invoke the factors which to all intents and purposes may be taken as of themselves non-existent, assuming of course that they are in a state of neutralization so that no phenomena are observable. We thus arrive at a more or less philosophical issue in pressing the argument to the extreme, but a step in this direction is of interest.

Considering mechanics in this connexion, if one body moves with another body, both in uniform straight-line motion, it is impossible to detect this movement by any experiments made between, or confined to the two bodies, even assuming that one body is the experimentalist equipped with suitable apparatus for measuring movement. Yet an outside observer or experimentalist not so restricted in his modes of measurement and regarded as relatively stationary, can detect a relative movement between himself and the original two bodies; but in making his measurements he has to employ Einstein's method, not Newton's, because his method ceases to be valid when extreme relative speeds are attained, though such great differential speeds are, of course, not necessarily involved in the case under consideration. It is merely to select the right method that this comparison is given. Having selected Einstein's method, we must expect the analysis of phenomena

to be in conformity with the generalizations involved in the theory of relativity. This leads to the realization of all phenomena by differential effects; in fact to the specification of the universe and its parts in differential terms, and when there is no differentiation there is no phenomenon, in short, *nothing*. In this sense, and in this sense only, we abolish the æther. Eliminate the "differential," and nothing happens, nothing exists, so far as we are able to measure it. All facts reduce to those of measurement, for that which we cannot measure, broadly speaking does not exist—is perhaps neutral to our means of attack.

The reader will no doubt begin to question matters here, for he might ask, How can it be shown that gravitational attraction separates the electricities and thus makes its force evident?—for what is said reduces to this idea, at least, so it might seem, when worked out logically backwards.

The answer is not a complete one in this case, but the so-called abolition of anything by a process of neutralization does not destroy the respective things, or "magnitudes," so neutralized; it only makes certain field conditions non-existent in terms of positive or negative polar effects. If now this neutralized "something" can be the medium of certain phenomena, gravity for example, then a two-fold something apart from matter, in the usual meaning of this term, exists.* This conception is

* The present writer attempted to sketch a magnetic scheme of gravity along these lines and in suggestive harmony with Einstein's relativity theory, which scheme appeared in the *Chemical News* of April 20th, 1917. It amounted to this: Gravitational attraction might be defined as a second-order magnetic effect involving magnetic lines which are neutralized in the gravitational field, but these lines still represent elastic binding bands which have their origin in the electrons circulating within the atoms. These "bands" are only manifest in the anchored sense (Einstein's theory), where the "differential" comes into play in the respective atoms. These atoms may be close to one another or they may be separated by enormous spaces. Space, as space, makes no difference, but the

in harmony with the one-fold idea of the electron and the one-fold idea of the proton. Difficulties present themselves in discussions of this nature for as one is smoothed out another one as a pucker appears somewhere else ; however, we are not justified in assuming that the perfect blend of one proton with one electron would abolish the atomic entity involved. If this were possible, to accomplish the destruction of atoms of matter would become merely a problem of close combinations, as already indicated. An entity of this composition might possess, however, remarkable penetrating properties, for its stability would be so great that no differential effects could be brought into play. Rutherford remarks on this possibility as follows : " Under some conditions, however, it may be possible for an electron to combine much more closely with the H-nucleus [proton], forming a kind of neutral doublet. Such an atom would have novel properties. Its external field would be practically zero, except very close up to the nucleus, and in consequence it should be able to move freely through matter. Its presence would probably be difficult to detect by the spectroscope, and it may be impossible to confine it in a sealed vessel."

Here, as in the earlier chapters, the stability of the atom becomes a factor of importance, so that it is now possible to show that the closeness or firmness of the electron binding governs the stability of the atom, and this leads to a theory of atomic stability from the point of view of ionization and radiation phenomena, as will be seen presently.

From Bohr's studies and the low voltage required to remove an electron completely from some of the atoms, giving rise to the state of ionization of the atom, it is evident that the binding of the electron to its nucleus is not a bondage of fixed strength but

geometry of space has to be taken into consideration. Their effects are additive, so that attraction is governed by the masses involved,

varies from element to element, and in the same element there are levels through which the electron has to be brought to effect the ionization of the atom. Hydrogen is ionizable at a moderately low voltage, while helium requires the highest known ionization potential to remove one of its electrons from the atom. Therefore the looseness of the binding is indicated by the ionization potential. Bohr says (page 89 *loc. cit.*), "the binding of the electron in the hydrogen atom is sufficiently loose to account for the tendency of hydrogen to form positive ions in aqueous solutions and chemical combinations." From the potential required to impart sufficient energy to remove the electron from the atom, Aston ("Isotopes," page 106) gives the atomic stabilities in terms of ionization potentials as follows :—

Neutral H atom	. . .	14
Neutral H ₂ molecule *	. . .	4.3
Alpha particle (He ⁺⁺)	. . .	$> 3 \times 10^6$
Singly charged helium atom (He ⁺)	. . .	55
Neutral helium atom (He)	. . .	25

It will be seen how experimental magnitudes of various kinds are turned to useful account and how the structure of matter, including atoms themselves, is being explored.

It is of interest in this connexion to note that ionization may be influenced by the chance effect involving the removing of electrons from the atom, which would be greater, the greater the number of removable electrons in the atom. Barium would be more easily ionized in this way than sodium, for the former has two external electrons whereas the latter has only one. The reverse process of the electrical neutralization of barium and sodium may be considered sterically in the same way. For

* In the case of molecules the energy is that required to disrupt the combination of normal configuration, and it is not, strictly speaking, an ionization potential.

studies in this direction see Saha, *Phil. Mag.*, 1922, vol. 44, page 1128, and earlier papers on the ionization of the elements in the sun which are dealt with in the writer's "Atomic Theories."

It is well to appreciate that a given atom may have what might be termed a multiplicity of incipient ionization potentials, for the repeated application of the force involved in the process may remove the electron by stages further and further away from the nucleus until finally it may leave the atom altogether, when ionization is said then to take place. Considering the radiation emitted, this is supposed to occur when the electron is in the act of making a backward step towards the nucleus of the atom. There are a number of these steps possible in all atoms. The step potentials which induce cumulative ionization are of smaller magnitude singly than the single ionizing potential which removes the electron at one bound from the atom, if it may be so considered. Cumulative ionization, in other words, is not effected at one electron impact, but may be brought about by accumulative effects or impacts. For example, 4 volts will ionize helium in this way, whereas the normal ionization is six times greater.

From the above it will be seen how the coupling together of magnitudes has brought about a systematic means of exploring regions of extraordinary smallness, yet their quantitative numbers give rise to powerful effects, so that the expression "mighty atom" is collectively true. The limitations of theory become manifest, and yet these very limitations open the door into new departments, and the whole subject takes on a renewed life or interest. The next chapter deals with a few of these limitations.

SUMMARY

Magnitudes are the valuable assets of science, and beginning at the small end, the atom, the electron

demands first consideration. It may be either a one-fold or a two-fold structure, but it is essentially an entity characteristically atomic. The opposite electricities involved in the proton and electron introduce ideas of more or less perfect neutralization, and these matters are discussed at some length. The theory of relativity is made use of in bringing out the idea that measurements and corresponding effects, or even phenomena, have no appreciation without a relative state whereby it is made evident to the observer. Gravity is considered in the light of neutralization of field, yet linkage is obtained through the differential effects in the atoms themselves at each end of the space interval. The argument leads to protons and electrons in such close union that a penetrating atom is theoretically possible, and then stability of the atomic structure due to loosely bound and tightly bound electrons has to be considered. This then leads to the ionization potentials of atoms revealing their stability, for ionization in this case is the removal of the electron from the atom. Then finally the number of removable electrons in the atom introduces a chance effect recently discussed by Saha. Cumulative ionization is briefly touched upon in connexion with the magnitudes already indicated. Certain limitations in modern theories are given in the next chapter.

CHAPTER XIV

LIMITATIONS IN THEORY

IN scientific investigations, the extension of broad principles on the one hand and the limitations involved in the use of certain theories on the other make it necessary to be careful not to give full scope to such ideas without experimental checks at every step. One may think in terms so broadly formulated as to yield test ideas for use in experiment; at the same time one may set out in concise form some of the limitations as they appear at present. With the latter idea in mind the writer will venture to suggest in the following terms certain limitations to theory :—

1. *Classical mechanics* breaks down when, for example, extreme velocities are under relative observational measurement, because it does not take into proper account the relative and geometrically physical aspect of measurement itself, which has, as it were, a formulization of its own.

2. *Relativity*, which supplies the above formulization, breaks down, or it is not yet applicable, when considered in connexion with the structure of the atom if physical processes are not involved as conditioned by relative measurement requiring proper frames of reference.

3. *The quantum theory* breaks down when attempts are made to extend it to radiation apart from its origin, because this extension is not at present justified. The undulatory theory of light holds

the field as a phenomenon exterior to the atomic mechanism.

4. *The periodic law* breaks down at the rare-earth elements because it is, in the pure aspect as freed from certain details, fundamentally a *nuclear law*.

5. *The atomic number* as defining the element, breaks down at the rare-earth elements because it has been interpreted as defining the element as a whole, whereas, it only defines the net nuclear charge. It, however, defines the element in that it is an index number.

6. *The octet theory* breaks down in cases where disturbing factors arise.

7. *The displacement law*, as revealed by radio-activity, breaks down when changes occur without the accompanying radiations demanded by theory (e.g. β -ray changes in a few cases are absent), because the process of change is evidently obscured.

8. *The whole-number rule for isotopes and atoms taken as isobaric isotopes* breaks down in some cases because disturbing factors in the measurement or in the atom are not taken into account.

9. *The Bohr atom* breaks down in theory when attempts are made to co-ordinate it with the octet theory, involving practically stationary electrons, because probably in these cases the limiting conditions are not fully appreciated. See discussion to follow.

The fourth statement above, in respect of the periodic law, calls for some explanation. It may be stated that this law is rigorously true for the nuclear parts taken in terms of net positive charge as the periods lengthen in accordance with certain rules; but the chemical properties, particularly that of valency, are conditioned by the external electrons in the atom. This external binding of electrons fails to follow the step-wise regularity in the case of the rare-earth elements, and consequently the periodic

law, as a valency law, breaks down in this instance. The cause of this change, or want of change, as it might be termed, is still obscure. The use of electrons instead of positive charges or protons has been resorted to in periodic schemes with good results, as shown by Table VI on page 34. See also Table II shown in Chapter I on page 14.

Further examples of this kind might be found, but it will suffice to give the foregoing illustrations in order to show how rather precise theories have to be used within limits if their strength is to be maintained. It is necessary therefore to distinguish between broad theory and the more restricted models which generally have some provisional label attached to them. For example, such a label might be: "Use in certain cases as our knowledge is too limited to guarantee results in all cases."

Of great interest is the conflict between the octet theory and the Bohr atom, for the latter gives such a satisfactory explanation of so many experimental facts of spectrum analysis that one is forced to regard Bohr's theory of the atom to be true in the main. The octet theory of valency as developed by Lewis and Langmuir, on the other hand, accounts for, or co-ordinates, many facts of chemistry, in particular the valency relations as already indicated, that it must be near to the truth. It is true that the Bohr theory is founded on the behaviour of the hydrogen atom having only one planetary electron, but the difficulty lies in extending the theory of planetary orbits to the electrons of the atoms of other elements which are supposed on the octet theory to be confined to positions of approximate rest when the atoms enter into chemical combinations with each other.

Inasmuch as the Bohr theory is founded on the spectrum of hydrogen, it might be assumed that with one comparatively free electron, situated some distance from the concentrated nucleus, it would

be free to absorb energy and retain it while its orbit maintains its path of given size corresponding to the energy so represented. As previously stated (see Chapter VI), radiation is only emitted when the trajectory of the electron relative to its nucleus is altered in accordance with quantum energy equations.

When, however, other elements having atoms of more complex structure are considered, difficulties occur both in the Bohr theory and in its reconciliation with the octet theory. Physicists and chemists have attempted to remove these discrepancies in theory. For the purpose of this chapter, which deals with limitations in theory, the following views will be recorded. See paragraph 16, p. 137.

1. The electron, in the instance of hydrogen only, describing elliptical orbits round a positive nucleus, affords one type of activity.

2. In the case of helium, the electrons vibrate or oscillate in semi-circular tracks round a positive nucleus. This is a view put forward by Langmuir in the *Physical Review* of March, 1921, page 339. The reason for this type of electron motion arose from other considerations. The following is Langmuir's abstract of his own paper under the general title "Models for the Helium Atom":—

"(1) *Bohr's model* is unsatisfactory because it gives too great a value for the ionizing potential and it is not in accord with the optical and magnetic properties of helium. Now the chemical evidence suggests that each electron in an atom has its own separate orbit, and that these orbits are closely interrelated. Accordingly two new models are considered. (2) In the *double circle model* the two electrons are assumed to move in two separate, parallel, circular orbits. The model, however, is unstable, for the ionizing potential, computed by applying the quantum theory, comes out negative. Another objection is that the magnetic moment is not zero. (3) In the *semi-*

circular model each electron is assumed to oscillate back and forth along an approximately semi-circular path in accord with classical mechanics, each being brought to rest at the end of its path by the repulsion of the other. Assuming the maximum angular momentum of each equal to $h/2\pi$, the absolute dimensions of the model were computed. The total energy comes out less than for the Bohr model, and the ionizing potential, 25.62 volts, agrees closely with the experimental value. The magnetic moment is zero.

"Application of the Quantum Theory to Coupled Electrons.—The success of the semi-circular model in giving the correct value for the ionizing potential of He suggests that in the case of coupled electrons the quantum theory should be applied not to the momentum of the individual electrons according to the relation

$$\oint p dq = h/2\pi,$$

but rather to the momentum which, by being relayed from one electron to another, passes in each direction around the nucleus."

This view has not met with general approval; in fact, more recent investigations seem to strengthen Bohr's theory, but it serves so well to illustrate the limitations involved in theory that prominence is given to it here.

3. The electrons in their octet positions absorb and radiate energy by such vibrations as enable them to retain their "corner" positions approximately.

4. The electrons revolve in small orbits, the axes of which are in cubical symmetry.

Considering now these four views, it will be seen that the *first* represents one extreme, the *second* a mean, and the *third* the other extreme, while No. 4 is probably untenable. In other words, we are

dealing with (1) the circle or ellipse, (2) the semi-circle, (3) the very restricted movement or vibration.

In the whole domain of science involving energy problems incompatibilities of this character occur. A few instances are:—

1. The quantum theory and the ordinary theory of radiation are in conflict at one extreme, while at the other they practically blend.

2. The theory of relativity is in conflict with the classical mechanics at high relative speeds, while at slow relative speeds the blend of the two is practically perfect.

3. The ordinary theory of valency is in conflict with the octet theory in certain cases, but the latter agrees with the former in other cases. It is an advantage not to have to change theory in passing from one extreme to another, and the theory which covers the whole range of phenomena is in general the truer theory. In this case the octet theory is to be preferred, as is Einstein's theory in connexion with moving bodies, etc.

Or again the following is to be noted:—

1. Fractional atomic weights were cleared up by isotopes, although calculations had been made to show how the fractional part of the atomic mass could be accounted for by energy conditions.

2. The discrepancies between Newton's calculations and the observed motions of bodies—electron emissions and the planet Mercury—have been cleared up by Einstein's theory, which formulates the relative view involved and the field conditions in the case of the planet.

3. The octet theory clears up certain outstanding difficulties of the older valency theories.

It is of interest here to record, at the time of this writing, that the second successful eclipse experiment has confirmed the bending of light from the stars in grazing the sun, although at least one of the principal astronomers engaged in this work was rather

CONFIRMATION OF RELATIVITY 129

prejudiced against Einstein's theory. The mean value for the displacement of the images on the photographic plates was in exact agreement with Einstein's figure, but this "exactitude" in itself was a coincidence, for experimental values were too wide apart to afford a true mean figure, but this theory is now confirmed.

APPENDIX I

THE PROBLEM OF THE SYNTHETIC PRODUCTION OR TRANSMUTATION OF ELEMENTS ON A COM- MERCIAL SCALE, AND SOME IDEAS ARISING THEREFROM

1. Radio-activity reveals the fact that the chemical properties of certain elements undergo a progressive change as they give off alpha and beta particles. This being well known, the point to be made here is that these changes are due to the arrangement or number of electrons in the outer part of the atom. It is true that the initial change is deep-seated in the atom, for it is believed that it originates in the nucleus, then the outer electrons readjust themselves in terms of number, and this gives rise to the valency changes observed in the case of these radio-elements.

2. Passing now to another line of study, the chemical character of an element as regards valency in particular has been elucidated by the well-known octet theory of Lewis and Langmuir. In this case the outer electrons of the atom take up positions best represented by the positions in space of the corners of a cube, but the imaginary cube is not always fully saturated with electrons. In lithium one corner only is supposed to be filled, in beryllium two, and so on until all the corners hold electrons, the greatest number being 8—disregarding polar electrons in the case of those atoms of Group VIII, and perhaps other subsidiary considerations such as those discussed in paragraph 28 below. In the case of a fully-filled cube containing 8 electrons in its outer shell there is no affinity for more, and the

atom is electronically saturated. From this circumstance it has been deduced that the inert gas atoms He, Ne, Ar, Kr, Xe, Rn, Tn, An, are non-active chemically because they contain a full complement of electrons in their outer shell.

3. There is another fact of interest in this connexion. Rydberg has deduced a formula for evaluating the atomic numbers of the respective inert gases, which is sometimes expressed in terms of electrons. This formula has already been given in Chapter III. The atomic number may be regarded from the classification point of view as a place in which all atoms chemically alike fall. For example, Rn, Tn, and An are isotopic as these are alike chemically. The word *chemically* has a widened meaning in this case, since it implies that the likeness is fundamentally due to a similarity in the net positive charge of the nucleus of the atom. This holds true in the instance of chlorine, which has two isotopes, and the net nuclear charge is the same on each, and they are chemically alike too, as they should be, for they have the same number of external electrons—in this case 7.

4. Now if by some procedure one could alter the number of external electrons on a given atom its chemical nature would be altered. In the case of carbon, which is regarded as a cube with only four electrons in its outer shell, it could be altered chemically to an inert atom like neon if four more electrons could be attached to the four vacant corners of its cube. As a first thought one might expect that an arc struck between carbon electrodes would furnish an abundance of free electrons, for the electric current between the poles would be a rapid passage of electrons. It is true that carbon vapour would be present in, or adjacent to, the crater or part of the arc which is raised to the highest temperature, about 4200° on the absolute scale. Without discussing the vapour phase involved, it is sufficient

for the present argument to imagine an abundance of carbon atoms in the arc, and these would be mixed up with free electrons. Why do not these electrons attach themselves to the corners of the carbon octets and form atoms chemically different from those of carbon proper? As an extreme, if all the corners were filled with electrons an inert atom would result, but this condition does not appear to be the case, at least to any appreciable extent.

5. To visualize mechanically the reason why, according to *one* view, this change of atom is not brought about, one may consider another subject vastly different in magnitude, but having certain features in common which will be considered next. The reader should bear in mind that various factors are being considered, and that in the conclusion of the argument certain ones may be rejected.

6. In the case of comets with trajectories round the sun they may pass at their perihelion close to this huge body in traversing out their elliptical orbits round it, and they are seldom captured by the sun. The cause of this phenomenon is easier to appreciate if one considers Einstein's theory of relativity, for, according to this theory, all heavenly bodies of a certain class, comets and planets in particular, have a path of their own pre-determined as it were by the gravitational field of the sun and by their masses and velocities; otherwise everything would fall into the sun. This is not easy to understand in reality, but accepting this dictum of Einstein, it will be seen that bodies moving with great velocities do not collide as readily as one might imagine would be the case. It is not necessary to invoke Einstein's theory here, but his treatment of such problems involves the above idea.

7. Returning now to the carbon experiment, it is not difficult to imagine the electrons *flying* *

* This may not be an accurate term, but let it represent great kinetic activity, as would be the case if the electrons were more or

across the gap between the carbon poles with a great velocity, even if they are partly carried by the carbon particles of the vapour, and if they are to be properly captured by the carbon atoms they would have to collide with them and come to rest in the carbon atoms. Here is a sun and comet case on a small scale, for the electrons are like comets and the massive nucleus of each carbon atom is like a sun. It may therefore be assumed that on this view combination is rendered very difficult, if not impossible.

8. There are cases, however, of electrons detaching themselves from one atom and attaching themselves to another atom, as in the instance of a sodium atom meeting a chlorine atom. In this example the single outer electron on the sodium atom is supposed to take up its abode in the single gap of the chlorine octet. The chlorine octet is then completely filled with electrons, and it would tend to resemble argon in respect of chemical inertness, but the change-over under conditions of contiguity is not quite so simple as this, as the presence of the sodium atom represents a positiveness in proportion as it parts with its electron, and in electrolytes, these two types of atoms (ions) drift apart, the water of the electrolyte forming a sort of buffer between them. Remove the water and they come together again. Thus it will be seen that potentially new or modified atoms are actually formed, but the conditions are such as to make it impossible to

less associated with the carbon particles which are in slower movement. K. T. Compton (*Phys. Rev.*, 1923, vol. 21, page 266), remarks : " That the current of the arc is chiefly thermionic in origin, consisting of the electronic emission from the cathode plus a relatively small current arising from ionization of the gas by these electrons. This ionization is essential, because positive ions are necessary in sufficient number to create a positive-space charge round the cathode, thus permitting the escape of electrons from it. All physicists now concur in the view that electronic emission from the cathode is of primary importance in the arc.

recover them by themselves as new atoms. By extending this idea to a different type of electrolyte from that indicated, other factors would have to be taken into account, so that the above statement is in the nature of a simplifying assumption. In these cases, however, the activities of the electrons are not the same as in the carbon experiment according to the present argument.

9. Whether it would be possible to introduce a buffer in the carbon experiment so as to reduce the activities of the electrons and actually to manufacture new elements is worth considering, if only to press the argument further so as to see whether any new difficulties would arise.

10. Liquid argon has of course been prepared, and some years ago F. Fischer and F. Schröter (*Berichte*, 1910, vol. 43, pp. 1442, 1454) sparked metals in this medium with the view of ascertaining whether any argon compounds could be formed. No results were recorded which could be regarded as definitely indicating compounds. Suppose now that carbon is sparked in liquid argon, and owing to the presence of the latter the electrons were slowed down sufficiently to enter into the outer shell of the carbon atom, partly on account of the heat energy being appreciably absorbed by the liquid; suppose that a few atoms were fully loaded with electrons, then there would be formed an inert atom of mass 12 with an atomic number of carbon, viz. 6. Such an atom would not be in accord with Rydberg's law. In weighing this probability it must be remembered that the word *law* is often an unscientific term if it is regarded as absolute in every sense. Nature may never have produced the combination indicated by this experiment, and, moreover, the Rydberg law may only be true as regards appreciably quantitative results: a residuum of abnormal elements might still exist.

11. In this connexion Sir J. J. Thomson (*Roy.*

Soc. Proc., 1922, vol. 101, p. 290) obtained by means of a positive-ray analysis of the heavier constituents of the atmosphere masses of 163 and 260, but they were probably Kr₂ and Xe₂, existing as transient compounds formed under the electrical conditions obtaining in the apparatus employed. It is evidently easier to remove electrons from atoms—hence arises the phenomenon of gaseous ionization—than to introduce them permanently into such places as indicated by the octet theory, or by any other theory, as a matter of fact. Thomson's results would be explained if single electrons could be removed completely from these atoms, thus reducing them to quasi halogens. Such atoms could then combine by sharing electrons in each other's octets in the usual manner. See, however, page 149.

12. On the whole this line of study thus far developed does not seem to point to the artificial production of new atoms commercially, though there is a remote possibility of this being eventually accomplished. The question here arises, Is there any sound argument which can be brought to bear upon the above possible case and, in common parlance, settle it one way or the other?

13. The *probability* of certain events happening seems a likely line of investigation. Everything is so orderly in the whole atomic scheme, including the periodic law, the atomic-number sequence, and the definite places for all known isotopes, that if the atoms could be changed chemically in the manner indicated above, then such atoms would have been produced in small quantities. In short, the probability of such events happening seems so remote as to render the experiment cited as likely to be non-productive of results.

14. Assuming this to be the case, one is led to regard the 4 electrons in the carbon atom, for example, as a stable combination which cannot be permanently altered without altering the nucleus of the atom,

so that the octet theory becomes in a sense devoid of reality when the atom is considered by itself. *The vacant corners are not places where electrons can be permanently or immutably fitted without some neighbouring atoms present to stabilize the combination.*

15. So far the octet theory, as a static scheme, has been tacitly understood. Suppose, however, that the Bohr atom is the true one, and the octet theory is more a convention than one would imagine, then other considerations have to be taken into account.

16. The idea here is that the electrons describe various elliptical orbits round the nucleus of the atom, and it is these paths which serve to link up contiguous nuclei, so that in effect the octet theory is realized, but the mechanism is not static—the electrons are always in orbital motion if it may be so described. In other words, or in other respects, the sharing of electrons according to the octet theory is effected in the Bohr-atom theory by the electrons describing paths which loop together two or more nuclei, so that several atoms are in combination chemically by reason of the linkages arising from the lacings of the orbits round contiguous nuclei; or, perhaps, to state it more accurately, the linkages of the electric or electromagnetic fields arise from the contiguity of the orbits which give effect to the said fields.

17. On this theory one would expect the above experiments to fail in producing new elements from stable elements, or from those more or less stable, because the Bohr system of orbits has reached its limit of structural stability in each atom, and the shooting in of another electron would not in this sense give rise to a stable combination so that the newly-introduced electron could find its level, so to speak, in the atom. Something more than the electron must in this case be introduced in or removed from the system, namely, a proton, and this implies

a process difficult to realize experimentally on a grand scale; and if it were realized, probably a normal element or isotope would be produced, but not an abnormal one, as in the case discussed above. See paragraph 19.

18. From this study one might deduce that the nucleus of the atom expresses in terms of atomic number the basic determining factor in atomic architecture, and in reality the periodic law is one which has its truest expression in the nuclear magnitudes known as the atomic numbers. In brief, the periodic generalization is fundamentally a nuclear law involving the periodicity of atomic numbers, and the outer-electron schemes are secondary states the stability of which in terms of electron number is determined by the nucleus, i.e. its structure. When, however, atoms come together in chemical combination the joint effect of two or more nuclei, operating through their external electrons, gives effect to combinations involving the sharing of electrons which become a stable system within the limits determined by the joint nuclear magnitudes; hence the utility of the periodic law in affording a classification of these magnitudes in such a way as to make it possible to pre-determine combinations.

19. Rutherford's experiment in firing helium nuclei (He^{++}) into normal atoms and dislodging hydrogen nuclei or protons therefrom is of course a process of artificial atomic disintegration, but the altered atoms are produced in infinitesimal amounts, so that we are still very far from producing appreciable quantities of atoms by changing one normal type into another. Rutherford's work in this field is, however, of great interest, representing one of the monumental achievements of science.

20. On the Bohr theory—based on Rutherford's earlier work and views—the problem can be approached by another line of study, for the known ionization potentials of the atoms give a clue to the

stability of their outer electrons. In spectrum analysis the displacement of electrons in the atom to positions further and further removed from the nucleus, by thermal stimulus, has been extensively studied. Helium with its more strongly bound electrons is difficult to ionize on this account, whereas hydrogen is easier to ionize, and its single electron can be completely removed from its nucleus by moderate thermal stimulus. Other examples might be cited.

21. Considered electrolytically, the fact that carbon does not form ions shows that under the conditions prevailing in an electrolyte the electrons in this case are firmly held to their nuclei. On the other hand, those elements with only one external electron, the alkali metals, are easier to ionize electrolytically.

22. These facts seem to confirm the views above given: that the manipulation of the external electrons does not in itself afford a probable means of producing elements synthetically, since the nature of the nucleus, as well as the disposition of external electrons, whichever theory of the atom be adopted, determines or characterizes the element; and to change the nucleus by removing protons by any artificial means would represent almost an impossible experiment to carry out on a scale which would yield "new" elements in appreciable quantities.

23. If, on the other hand, an electron in the *nucleus* of the atom could be removed, then as in certain radio-active changes an alteration of chemical type would follow, as indicated in the first paragraph above. Such an atom might be sufficiently stable for commercial uses, and herein seems to lie the most promising method of attack; but, of course, to produce atoms of this type in appreciable quantity might be impossible. One reason for regarding this line of attack with some favour is that probably less energy would be required to displace a nuclear

electron than to displace a nuclear proton, as Rutherford has done, if one is justified in regarding Rutherford's proton as coming from the nucleus proper, as appears to be the case in some of his experiments.

24. A consideration arises in respect of this deduction, if it may be so regarded, for the electrons definitely assigned to the nucleus represent perhaps a convention, since it may mean only those which at a given time (any instant) are near to the nucleus taken as a pure positive structure of exceedingly small dimensions. Similarly the outer electrons may be the number which reach at a given instant of time a high-level zone round the nucleus. In the example of helium the scheme might be shown thus ;—

$$\begin{array}{rcl} \text{Nuclear electrons} & = & 2 \\ & \updownarrow & \\ \text{Outer electrons} & = & 2 \\ \text{Positive charge of 4 due to 4 protons.} & & \end{array}$$

This atom would represent the normal helium, *not* having lost completely one or two electrons. It will be seen that at one instant the outer electrons, if they were labelled, would become the inner ones, and, correspondingly, the inner ones would become the outer ones. This suggestion is of doubtful significance, as it is difficult to reconcile it with certain properties of the atoms, for, according to the present views, electrons describe close orbits (a few practically circular) like the planets and also great orbits (more elliptical generally) like comets ; and, carrying the illustration further, when the comet does not return to its original sun complete ionization will have taken place. To effect ionization in the case of hydrogen the energy required completely to remove the electron from its innermost orbit to infinity is 215.6×10^{-13} erg.

25. There is a germ in the foregoing idea that is of possible interest from the standpoint of radio-

activity. The expulsion of negative electrons from the radio-atom is supposed to have its origin in the nuclear part of the structure. If the above conception in question represents a modicum of truth, then the cause of the electron (beta particle) leaving the atom may still have its origin in the nucleus, for some chance coincidence, representing a conflict in the many orbits, culminating, as it were, at the nucleus, might give one electron a new trajectory which would be such that it could not return to its nucleus, while at the same time some redistribution of the others takes place as a result of the disturbance. If this conception in general be true, how then is one to account for the expulsion of helium units which are helium atoms minus the two outer electrons. It might be assumed with some degree of probability that this phenomenon arises from built-on structures to more normal atoms, so that the radio-atoms are complex in having structural irregularities of this kind, which may be represented as additions pure and simple, or even depletions in certain cases, which would sufficiently destroy the homogeneity of the structure to permit of parts being thrown off of appreciable magnitude, as represented by the alpha particles. See pages 109, 110.

26. Returning to the main subject of this appendix it will be seen that at every step there arises a difficulty which makes it impossible to reach any definite conclusion as regards the best line of attack in altering one element into another in appreciable quantities. It would appear that to drive electrons permanently out of the atoms in any quantity the nucleus would have to be operated upon, and more than this it does not seem safe to suggest. Stating this in another way, the electrons apparently have a greater density distribution round the nucleus of the atom, and the chance of bringing about a conflict of forces, so to speak, would be greater there than in the outer regions of the atom where chance conflicts would be

reduced to a minimum ; but to offset this circumstance the carrying out of a broadside attack is made difficult by the shielding action of the outer electrons. It would seem that the most promising penetrating weapon would be the electron. Quantitatively, and therefore commercially, the problem looks difficult, for it would be akin to the destruction of a building—or its remodelling—by picking out the grains of sand in the mortar between the bricks. There are too many bricks, or, in short, too many atoms to make the process a tempting one.

27. These discussions, however, may be helpful in other ways, as they show, though imperfectly, the wonderful mechanism of things too small even to be seen.

28. One or two suggestive ideas arise from this line of study which will be touched upon here. Considering the arc carbon, as used in the hypothetical experiment discussed above, it is itself a conductor, and yet the 4 valency electrons on the carbon atom are very stable. Where then do the conducting electrons come from, as it is only conceivable that conduction can take place by one electron displacing another freely or easily and progressively? There must be loosely-lodged electrons in some vacant corners of the cubes not utilized in self-combinations which can be moved along in the process of conduction—a sort of part-lattice movement taking place. The presence of such electrons would, moreover, account for the limit to the positiveness of an alkali-metal atom. A lithium ion, for example, would be represented as Li^+ , and *not* as $\text{Li}^{+++++++}$. The true representation might be $\text{Li}^{+++++++}$, and thus account for the vacant corners on the cubes not functioning until the conducting electrons are displaced by the more forceful ones backed up by their nuclei. If now the minus signs written below the + signs are converted into little arrows thus \rightarrow they would represent the flow of the conducting

electrons when the necessary urge (E.M.F.) was introduced locally in a completed metallic circuit. Referring to the writer's "Atomic Theories," page 136, the types of atoms shown would on first consideration then become so-called neutral atoms owing to the "conducting" electrons filling the + corners, but they (O and N) would not be conductors of electricity, because they would combine chemically with themselves by sharing "valency" electrons in their octets; but it may be necessary to distinguish between atoms which are never individually free until their momentary passage into combination and those normally and ionically free, like the atoms of lithium for example. In this case the presence of conducting electrons would have to be considered as doubtful in the case of oxygen and nitrogen atoms. There is, by the way, probably only *one* kind of electron, the terms *conducting* and *valency* referring to the circumstantial conditions existing, as is obvious from the foregoing. The + corners above need not represent in each case the full + charge corresponding to one proton. Some of the ideas brought out in this appendix lead naturally to a specification of an element; which is given in a further Appendix II.

APPENDIX II

THE SPECIFICATION OF AN ELEMENT

The term *element* connotes not only an indefinite number of atoms of like type, but it may include a mixture comprising atoms differing in mass yet chemically alike, and this may be specified in terms of species. Isotopes represent an example in this respect. Chlorine, for instance, is made up of atoms alike in type but differing in mass, so that, to be precise, there are two species of chlorine atoms.

In radio-chemistry the radio-active properties differentiate atoms which would, by all other standards, be alike. For instance, two distinct radio-elements may be made up of atoms all alike chemically, but prospectively different owing to different radio-properties. Moreover, as they may arise from different lines of disintegration their labelling would be modified on this account. This will be seen by referring to Table VIII on page 107.

Strictly speaking, the periodic table is a classification of *atoms*, not of elements, for such elements as oxygen taken in bulk would represent a substance characterized by the combination of atoms in pairs. Liquid argon and liquid oxygen would in several respects be alike; whereas, single atoms of oxygen would have very different properties from those of argon. This distinction does not impair the value of the periodic classification, for it indicates the combining characteristics of the atoms as such, so that when they do combine the result is as would be predicted by the information systematized by the table, especially when certain laws arising from the

SPECIFICATION OF ELEMENT 145

periodic classification are taken into account, such as (1) ionization and (2) sharing of electrons in chemical combination, these being main factors to consider as the occasion arises.

When studying the elements, it is helpful in their specification to bear in mind the following main points:—

(1) The valency characteristics of the atoms of an element are elucidated by the Lewis-Langmuir theory, referred to briefly as the octet theory, as the octet principle is a predominating one in the theory.

(2) The normal nature of the element, so that when the atoms are manipulated their behaviour will be better appreciated.

(3) The influence of free electrons apart from those which are more or less permanently fixed in the valency shell of the atom.

(4) The influence of catalytic bodies, water, for example, in rendering possible combinations of atoms which would not start if they were absolutely free from any catalyst.

(5) The dynamic activity of the atom or molecule as governed by its size or mass plays a part in certain reactions.

(6) The strength of the molecular combination—that is to say, its resistance to breaking up by impact.

(7) The tendency of certain atoms to revert to certain combined types rather than to others, owing to the electron number in the outer shell of the atoms, and the stabilizing influence of their nuclei.

(8) The periodic occurrence of certain types of atom which are different from the more normal ones. Group VIII affords an example in this respect.

(9) The atomic structures as revealed by X-ray analysis involving atomic numbers.

(10) The building up of the atomic edifices by a system of electron movements and bindings as revealed by spectrum analysis studied in connexion with other phenomena.

146 THE CHEMICAL ELEMENTS

(11) The relative quantitative evaluations of certain elements studied with reference to those missing in the periodic table. This list may be elaborated and extended.

The specification of an element may thus become a complicated scheme, though certain parts of the plan are comparatively simple.

Many of the points in the above list are brought out in different chapters or parts of this book and in the writer's "Atomic Theories."

APPENDIX III

ISOTOPES: RECENT ADVANCES MADE BY DR. F. W. ASTON

In the *Philosophical Magazine* for May, 1923, Dr. Aston records officially further results in the mass spectra work on the chemical elements, and some negative experiments are given which are of interest. These are given here.

One of the most helpful advances has been the use of more sensitive plates termed *Schumannised plates*, because the treatment of the plate is like that of an ordinary one when the gelatine is removed as far as possible, but in plates used by Dr. Aston the dissolving off of the gelatine, by means of dilute sulphuric acid, is not carried so far.

Helium.—At the suggestion of Prof. McLennan, samples of helium from Canadian gas wells were examined for isotopes, but none were observed. In this connexion it may be noted that, should there be any He^{++} atoms present during analysis, these would register themselves on the plates as if their mass was $4.00/2$, which lines could be checked against hydrogen lines representing a mass 2.016 . By this test the decimal difference in mass could be accurately determined, but no He^{++} lines could be found, presumably on account of the high ionization potential of 80 volts, which reduces to a negligible figure their percentage numbers in the mixture.

Nickel.—Sir J. J. Thomson had used nickel carbonyl, but in the quantities then employed it decomposed, and the metal was deposited on the walls

of the discharge tube. Dr. Aston has overcome this difficulty by diluting the nickel carbonyl with carbon dioxide and regulating the discharge current to a safe limit. The chemically determined atomic weight is 58.68. The isotopes recorded were 58 and 60 in such proportions as to give the atomic weight as a mean figure.

Metallic chlorides.—Metallic chlorides are particularly satisfactory to handle in the vapour state owing to their stability, but these have a violent action on rubber and tap grease. The result, apart from undesirable compounds, is the release of free chlorine. Consequently there is a "perfect maze of lines filling every successive unit place and effectually screening any clear vision of the lines of the element under observation." Moreover, chlorine forms hydrogen addition products, chlorine itself having isotopes, 35 and 37, and for every type of combining particle there will be *two* lines for the monochloride, *three* for the dichloride, and *four* for the trichloride, etc.

Titanium.—On account of the foregoing difficulty titanium chloride gave spectra of great complexity and no proper identifications of isotopes could be made. Two promising lines were recorded, but these were identified from previous experiments as being probably due to tap grease.

Chromyl chloride.—This chloride was "even more hopeless, for its action on tap grease and wax was so rapid as to make it quite unworkable."

Lead ethide and zinc methide.—No lines were recorded with these compounds, the probable reason being the abundant liberation of carbon and hydrogen compounds from the decomposing ethide or methide. As an instance of the delicacy of the method, a single iodine line 127 appeared when using the vapour of zinc methide, which was supposed to be quite pure, being colourless. Dempster's fine work on the isotopes of zinc is referred to.

Xenon, krypton, etc.—This method was successfully used to verify the purity of the xenon from krypton contamination, the sample being one provided by Dr. R. B. Moore, as used in his density determination, thus rendering the density determination free from any criticism on the ground of krypton being present. The value deduced from this determination is 130.2. Dr. Aston considers it a little on the low side, but the mean evaluation in the case of isotopes is not accurate enough to carry weight against a good chemical or density determination. Excellent lines were obtained on the Schumannised plates, and suspected xenon lines 128 and 130 were confirmed.

Dr. Aston here refers to the search for inert gases of higher atomic weight than xenon, and mentions that in this connexion two new components of xenon, 124, 126, were discovered.

It will be remembered that Sir J. J. Thomson (*Roy. Soc. Proc.*, 1922, vol. 101, p. 290) found by his positive-ray method two atmospheric constituents of apparent masses 163 and 260, and suggested that these might be due to molecules Kr_2 and Xe_2 .

To make this review up to date and fairly complete, the following abstract from Dr. Aston's paper, read before the Royal Society, entitled *A Critical Search for a Heavier Constituent of the Atmosphere by means of the Mass-spectrograph*, is here reproduced:—

"A critical search for a gaseous inert element heavier than xenon is described, in which the residues absorbed in charcoal from over 400 tons of air are dealt with.

"The final analysis is made by means of the mass-spectrograph. The result is negative, and indicates that such an element certainly does not exist to the extent of 1 part in 10^{15} of air, and probably not to the extent of 1 part in 2×10^{16} parts of air by volume.

"Faint bands observed in the region corresponding to masses 150 and 260 are described and their origin

discussed. The first of these is shown to be due to a complex molecule of mercury with a multiple charge, but no conclusion is reached in the case of the other.

"The results of the experiments are not in accordance with the presence of molecular krypton and xenon in the air, recently suggested." See above.

Tin and the whole-number rule.—The earlier work on the isotopes of tin is now confirmed, the values being 116, 117, 118, 119, 120, 121? 122, 124. The intensities of the lines are such as to render it improbable that any of the lines are due to hydrogen addition products except the value 121, this being very faint on the plate.

In this experiment tin tetramethide was used, which was supplied by Sir W. Pope. The evidence that the above lines were due to tin isotopes is supported by the presence of lines 15, 30, and 45 units higher up in the mass scale by reason of compounds SnCH_3 , $\text{Sn}(\text{CH}_3)_2$, and $\text{Sn}(\text{CH}_3)_4$. These lines show exact whole-number differences, but "when compared with other lines on the plate they give values less than whole numbers by 2 to 3 parts in 1000." The presence of xenon lines and those of tin monomethide amongst them made it possible to compare the registration of the tin lines with them. If the xenon lines, 134, 136, represent whole-number masses, then the compound $\text{Sn}^{120}\text{CH}_3$ should lie exactly midway if the tin isotope 120 is a whole number, but it is displaced to the left slightly so as to "coalesce partly with Xe^{134} ," making this line appear broadened.

Dr. Aston remarks as follows: "It seems impossible to imagine any instrumental defect which could give rise to this shift. There appears, therefore, to be no escape from the conclusion that tin and xenon cannot both obey the whole-number rule. It was realized and emphasized (*Phil. Mag.*, vol. 39, p. 624) that this rule was not to be expected to hold

with mathematical exactness owing to the packing effect, but it is very surprising that elements only differing by three units in atomic number should show so large a divergence. It seems probable that the divergence from the mean ($O = 16$) is greater in the case of tin than in that of xenon, but since the arithmetic sum of the two (supposing them to be of opposite signs) is only about three times the experimental error, satisfactory settlement of this point will have to be deferred till an instrument of higher precision is available."

Iron.—This element gives a volatile carbonyl (prepared by W. H. Mills), and thus makes it possible to obtain a record of this compound on the plate. A strong line was obtained, indicating that an atom of iron existed of mass 56. A fainter line giving a value of 54 was also recorded, which may be an isotope, but the line is so weak that iron may be made up entirely of atoms of mass 56, though the chemical atomic weight is 55.84.

Cadmium.—Cadmium, though easily vaporized, gives no lines in the expected region. In this experiment a quartz vessel containing the cadmium was lowered into the cathode-ray path by means of a winch. The metal was vaporized, and it condensed on the walls of the tube, forming a bright mirror.

It was noted that mercury was completely eliminated from the discharge by the presence of the cadmium, and it did not reappear "so long as the cadmium mirror remained on the walls of the discharge-tube." A method of eliminating mercury is thus discovered.

Thallium.—As part of the above experiment, this element was tried without results, and it is probable that the cadmium layer removes the thallium vapour as effectively as it does mercury.

Selenium.—The unsuccessful use of selenium hydride (*Phil. Mag.*, vol. 42, p. 140) led to the

volatilizing of the element itself, with the result that five strong lines were obtained, viz. : 76, 77, 78, 80, 82. There is a faint line at 74. These values were confirmed by a set of corresponding lines 12 units higher up on the mass scale; due to CSe ; also lines 28 units higher, due to $COSe$, were obtained, and some faint lines of CSe_2 were identified. It is to be noted that three selenium isotopes have the same masses as some of those of krypton. This is a case of isobaric heterotopes.

Tellurium and beryllium.—Pure tellurium was volatilized, yet no lines were obtained, but this failure is probably due to its high boiling-point and consequent low vapour pressure. Tellurium chloride was used without success.

Beryllium acetate was tried, but its immediate decomposition yielding a white oxide prevented this experiment becoming successful. G. P. Thomson's positive-ray analysis of this element, however, stands; there being only one value, 9, which is in close agreement with Hönigschmid and Birckenbach's value, 9.018.

Aluminium.—The chemical atomic weight of this element is now known to be 26.96, and it is therefore evident that in all probability it is a simple element, having only one mass value, 27. Dr. Aston remarks that as a rule odd atomic-weight elements have never more than two isotopes, and the occasional appearance of the line 13.5 is probably due to Al^{++} from the electrodes. The line 27 has, however, been observed. Lines 62 and 97, also recorded, indicate mono- and dichlorides of bodies of masses 27 and 28. The latter may be Si^{28} or CO, but the former is probably aluminium, and Dr. Aston says, "it is therefore reasonably certain that this element consists mainly of atoms of mass 27, and, since there is no evidence of atoms of lighter mass, the chemical atomic weight leads definitely to the conclusion that it is simple."

Chlorine.—In the foregoing experiments exceedingly intense lines, 35, 36, 37, 38, have been obtained, but no trace of a line at 39, and Dr. Aston concludes that the hypothetical isotope 39 does not exist.

Antimony.—Antimony hydride proved of no use, but antimony methide, prepared by Prof. G. T. Morgan, when introduced with CO_2 , gave values 121 and 123. With sufficient exposure similar lines appear 15 and 30 units higher up on the mass scale due to the mono- and dimethide respectively. Faint companion lines, 122 and 124, appear to be due to hydrides from their irregular intensities. The antimony isotopes seem to be in accord with the whole-number rule. The atomic weight as determined by Willard and McAlpine is 121.77, which agrees with the mean estimate of the above isotopes, judging from the relative intensities of the lines.

A table of isotopes embodying the above values is given on pages 2 and 3. Dr. Aston proposes to call the integers *mass numbers*, as it is evident from the foregoing that there are some cases where the deviation from whole numbers, though small, is still appreciable.

APPENDIX IV

IS THERE AN ELEMENT OF ZERO ATOMIC NUMBER?

I

The subject of atomic numbers is of great interest, and the existence of an element, if it may be so called, of zero number may be considered in this connexion. To discuss this possibility one must have some basis for the argument.

The following scheme, in the writer's opinion, is suggestive, and while the final values follow in general of necessity, when using Rydberg's numbers it shows that an *initial* element of zero atomic number could be introduced so as to give a series 0, 1, 2, 3, 4, 5, completed to its origin, as here shown.

SCHEME

Act. Elmts preceding :		
He = 2	At. No. He = 2.	2 - 2 = 0.
Ne = 2 + 7 = 9.	Ne = 10.	10 - 9 = 1.
Ar = 9 + 7 = 16.	Ar = 18.	18 - 16 = 2.
Kr = 16 + 17 = 33.	Kr = 36.	36 - 33 = 3.
Xe = 33 + 17 = 50.	Xe = 54.	54 - 50 = 4.
Rn* = 50 + 31 = 81.	Rn* = 86.	86 - 81 = 5.

Abbreviations : Act. = active, Elmts. = elements. At. No. = atomic number.

The term *element* represents some places or lacunæ which may never be properly filled ; but this observation does not apply to the elements below scandium according to the writer's studies given in Chapter III.

* Also Tn and An (emanations) which occupy the same atomic number place.

Considering, however, the existence of an element preceding hydrogen, it would find a place in many periodic schemes; for example, the one on page 34. In this case the series 2, 6, 10, 14 will be completed to its origin by introducing this hypothetical member.

In Bohr's recently published book, "Theory of Spectra and Atomic Constitution," page 70, a pyramid type of periodic table is shown which appears to be based partly upon one due to T. Bayley (1882), reproduced in Mellor's "Inorganic Chemistry," page 810. Bohr says: "Compared with usual representations of the periodic system, this method, proposed more than twenty years ago by Julius Thomsen, of indicating the periodic variations in the properties of the elements, is more suited for comparison with theories of atomic constitution." In this type of table the element in question could stand at the apex of the pyramid. Whether the table is a "wedge" or a "pyramid" seems to make no difference, but in the former type a numerical rule (4th paragraph above) may be used as an argument in favour of an element preceding hydrogen—that is to say, the displacement occasioned by the wedge arrangement lends itself to this treatment. It may be mentioned in this connexion, that the object of the wedge scheme was to correlate the chemical properties of the elements whilst giving the expansions obtained in the pyramid type of table, particularly on account of the rare-earth elements.

Now a certain peculiarity arises from the introduction of a new member at the beginning of the series. In the table on page 34 this element would fall into the zero group, yet it could not be inactive according to the above rule. Furthermore, an element before hydrogen of atomic weight 1.008 would presumably have to be a fraction. One must proceed cautiously in advancing new ideas, and it can probably be shown that there are just as many arguments against ~~as~~ for the existence of

such an element; and, therefore, no probable decision can be arrived at. The subject is, however, a very interesting one, and some further views will be given below.

NOTES

The above expression, "Rydberg numbers," refers to the atomic numbers of the inert gases, which may be calculated by the well-known equation due to Rydberg, already described in Chapter III. The expression, "pyramid table," is not to be taken in the solid-figure sense. It merely means that the table, as drawn, is suggestive of a pyramid, but perhaps a better name could be found. It is convenient to have names for the purpose of identification, though they may not be scrupulously accurate when applied to more or less elastic schemes such as periodic tables.

II

Referring to Part I above, it was assumed that when dealing with series numbers, they should, if possible, be completed to their origins. Two series were given, and in each case when they were completed as far as possible to their origins, i.e. without passing into negative values, they seemed to imply that an element should exist with zero atomic number; but there were other reasons given for doubting this possibility. The subject, however, merits further treatment.

It is of interest to consider this problem in its more realistic aspect. Numbers alone will not carry the argument very far. The figures shown in the scheme on page 154 had in themselves no remarkable significance; indeed, other numerical sets could be given, but the point made was that if there were two active elements preceding helium—hydrogen and one other, then the series as constructed

ran 0, 1, 2, 3, etc., instead of 1, 2, 3, etc., as would be the case if there was only *one* preceding element.

Atomic numbers, as is well known, are intimately bound up with the net nuclear charge of the atom, and since this is positive the number is thus associated with a charge opposite to that of an electron. This being so, the question arises—Where does the unit positive charge representing unit atomic number reside? According to modern views, based largely on the work of Rutherford, this unit would be the proton, and it resides in, or is, the hydrogen atom apart from its single electron exteriorly situated. Since the hydrogen atom can now be placed in the periodic table (see references in previous part), and it is possible to remove from it its single electron, it is not stretching matters to regard the proton as properly classified, especially since the atomic numbers are nuclear magnitudes. The electron belonging to hydrogen can thus be ignored in the placing of the nuclear proton.

The electron, however, is not as yet placed, and since it cannot function by itself as a positive entity, like hydrogen minus its electron, it is natural to conclude that it cannot possess a normal atomic number, though it may enter into the nuclei of atoms and condition them in terms of atomic number.

It may be jumping to a wrong conclusion to give the electron a zero number, but it is quite as reasonable a proposition as the assigning of its opposite type, the proton, to the hydrogen place, for in the latter case the hydrogen atom normally takes with it an electron. It might also be argued that since the atomic numbers are essentially positive electrically, the electron, if placed in any scheme, should have a negative place and not a neutral one, as represented by a zero number.

As a further consideration it is well to remember that the net nuclear charges of the atoms are to all

158 THE CHEMICAL ELEMENTS

practical intents and purposes their atomic numbers ; and, therefore, the periodic scheme is one involving the classification of atomic nuclei. The nucleus is, in fact, the predominant conditioning or controlling factor in the atom ; and the properties of all atoms seem to rest upon this nuclear magnitude as the sort of foundation on which the superstructure of the atom is built. The atomic numbers are magnitudes which govern the number and disposition of the external electrons that function in valency phenomena.

Another point to be considered is that in all the relations studied which involve protons and electrons there appears to be only one foundation, as it were, in the structural characteristics of matter, and all variations are due to those relative to that foundation. There are not two distinct electricities, but only one by comparison, which may vary from zero to a maximum value representing positiveness, the electron being the agent or entity which brings about this change.* If this is so, there can be no such thing as a negative atomic number, for the asymptotic limit, so to speak, is zero. The electric agent which brings about this change, the electron, cannot do more than neutralize a positive charge until it is practically zero. Since the relations studied are relative, this dual oneness of affairs is difficult to understand, and what appears to be a negative charge pure and simple must, perhaps, be judged in its relative or complex aspect.

It is not possible to pass through zero with atomic numbers, but the negative electron may be given the zero place in the system of representation, inasmuch as it can, in its most advantageous position, only neutralize a single unit positive charge to zero. It is true that the picture can be represented in the

* The word *electricity* stands for phenomena of considerable complexity, and this fact should be realized.

reverse way, making the electron the main factor, but this does not harmonize with the atomic-number conception based upon the positive charge of the nucleus of the atom which is fundamentally associated with its mass; or, at least, the discussion, to be consistent, must be from the standpoint of atomic numbers. Therefore, from the relative view given, there can be no *negative* atomic number, but it might represent zero charge, in which case the electron could be taken as a *zero-producing* quantity so far as atomic numbers are concerned.

It must be remembered that the series given on page 154 implies that the zero-atomic-number element is *active*, yet without a positive charge. The electron is certainly active in the chemical sense, as it serves as a bond of union in chemical combinations, and it is without a positive charge—it is relatively negative in fact, for its addition to a positive nucleus reduces the charge as already discussed.

The conventions of language involving terms denoting *opposites* should be used cautiously, as it is the phenomena which are to be pictured rather than the descriptive words as such (see notes below).

There is another development in this connexion as discussed by Rutherford and by Eddington and by Sir J. J. Thomson, affording a further view which will be given in the next section.

NOTES

It should be appreciated that the process of electrification consists in transferring electrons from one body to another. An electric current is a flow or drift of electrons. The positive charge seems always to be associated with matter in that the charge appears in proportion as electrons are separated from matter, the term *matter* here referring to the protonic structure in which the main mass resides.

III

IN pursuance of this study it is of interest to note that Sir E. Rutherford (BAKERIAN LECTURE, *Proc. Roy. Soc.*, 1920, A, vol. 97, page 377) suggests that it is by no means impossible for an atom of mass 1 to exist with zero nuclear charge. "On present views," quoting from the above lecture, "the neutral hydrogen atom is regarded as a nucleus of unit charge with an electron attached at a distance, and the spectrum of hydrogen is ascribed to the movements of this distant electron. Under some conditions, however, it may be possible for an electron to combine much more closely with the H nucleus [proton], forming a kind of neutral doublet. Such an atom would have very novel properties. Its external field would be practically zero, except very close to the nucleus, and in consequence it should be able to move freely through matter. Its presence would probably be difficult to detect by the spectroscope, and it may be impossible to contain it in a sealed vessel. On the other hand, it should enter readily the structure of atoms. . . ."

Prof. Eddington, in his book, "Mathematical Theory of Relativity," discusses this problem from the energy or mass side, and points out that the complete neutralization of a proton by an electron might give rise to a loss of mass that would pass out as electromagnetic radiation.

It will be seen that these ideas involve a nuclear atom of zero atomic number; only, in the case of complete neutralization, such an element would become more or less massless, if Eddington is correct in his surmise. See pages 90, 116 of this book.

In the case of *complete* neutralization, it is supposed that the electron and the proton can coalesce. Now Sir J. J. Thomson puts forward the view, which has been under consideration for some time,

that when the electron approaches sufficiently near to the positive nucleus then a repulsion sets in. Sir J. J. Thomson, in the *Journal of the Franklin Institute*, May, 1923, page 597, says: "I shall assume that the law of force between positive charge and an electron is expressed by the equation—

$$F = \frac{Ee}{r^2} \left(1 - \frac{c}{r} \right)$$

where

F = attraction between the charges,

E = the positive charge on the core,

e = the negative charge on the electron,

r = the distance between them,

c = a constant varying from one kind of atom to another; it is the distance at which the force changes from attraction to repulsion and is of the order of 10^{-8} cm."

Sir J. J. Thomson remarks that if the law of force is that just given, "then a number of electrons can be in stable equilibrium round a positive charge without necessarily describing orbits round it." In this connexion, Sir J. J. Thomson calls attention to Earnshaw's theorem: that no stable configuration in which the electrons are at rest or oscillate about stable positions is possible when using only the inverse-square law of distance. Furthermore, an example is given which makes planetary phenomena non-applicable to the atom, for in the case of Saturn's rings the particles do not repel each other as the electrons do. In this treatment of the problem it is assumed that the ordinary law of attraction applies at considerable distances, but when the distance becomes excessively intra-atomic, so to speak, then the law no longer applies, and this introduces a new law, as indicated above.

The argument in its present development leads again to the improbability of there being an atom

162 THE CHEMICAL ELEMENTS

or nuclear magnitude, of zero atomic number, and it is necessary to fall back upon the reasoning of Part II, in which the electron was the only entity that could have a place before hydrogen, and its zero atomic number was only acquired by virtue of its neutralizing quality, though this property is limited if the views of Sir J. J. Thomson are correct. In short, the electron cannot coalesce with the proton and form a stable system.

We have here a case of different scientists of great eminence working out different explanations of phenomena which seem at variance in some respects.

APPENDIX V

BRIDGING THE GAP IN THE SPECTRUM: NOTES

In Chapter X, dealing with radiant energy and the full-length spectrum, the diagram (Fig. 2) shows a *gap*. NICHOLS and TEAR (*Proceedings of the National Academy of Sciences of U.S.A.*, June, 1923) have now bridged this gap; and to give the reader a brief statement of this achievement, their paper is here described, after making a reference to MAXWELL's theory. It will, moreover, serve to supplement information given in Chapter X.

HERTZ's classical experiments with electric waves in 1888 not only paved the way for the development of wireless communication, but showed that these waves, as indicated by MAXWELL's electromagnetic theory of light, were waves of the same kind as light, for they could be bent by prisms and shown to be a part of a spectrum. The electric waves of HERTZ as he produced in his laboratory were 60 cms. long.

It was not until 1895 that LEBEDEV obtained electric waves which had a length of 0.6 cm. LAMPA about the same time had produced waves of 0.4 cm. in length. MÖBIUS, in 1918, confirmed the general results of the two foregoing investigators, but he came to the conclusion that their waves were respectively 1.0 and 0.7 cm. long. MÖBIUS, from experimental considerations, deduced evidence that in this case anything shorter than the above were ripples as distinct from regular waves.

At this time, following LANGLEY's researches on the solar spectrum, RUBENS and PASCHEN investigated the infra-red end of the spectrum and detected

164 THE CHEMICAL ELEMENTS

waves 9.4μ , which is sixteen times longer than the wave length of yellow light.

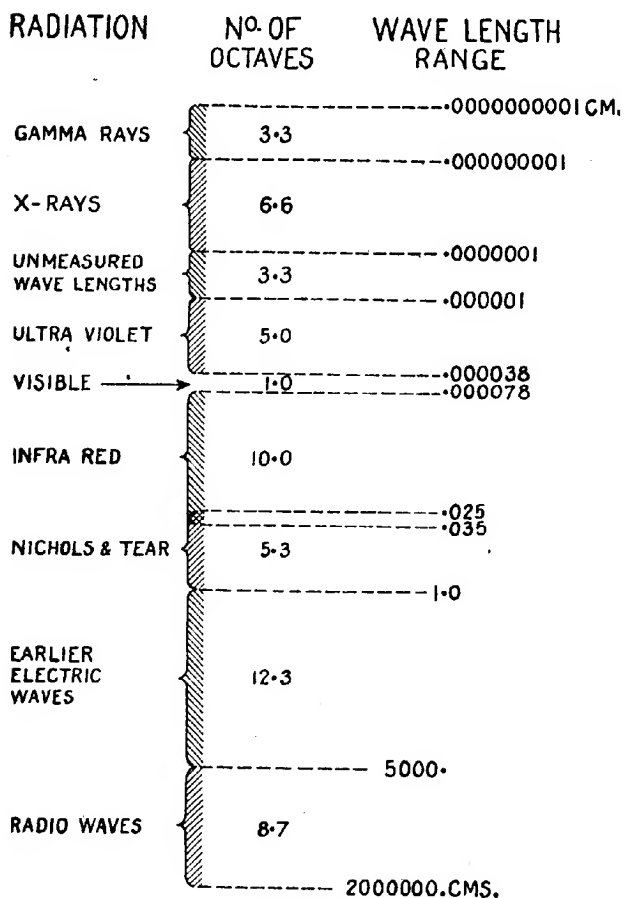


FIG. 3.

In 1897 RUBENS and NICHOLS, by means of a multiple-reflexion method, succeeded in extending

the boundaries of the infra-red part of the spectrum tenfold. Then the former investigator obtained a further extension by employing WOOD's method of focal isolation. Following on this, RUBENS and VON BAYER, in 1911, measured infra-red waves up to 0.032 cm. in length.

There remained a gap between the heat waves and those produced by electrical apparatus, but this gap NICHOLS and TEAR have now bridged by electrical waves, using a method which is briefly described in the *Proceedings* already cited.

The method devised involved the use of a NICHOLS radiometer (see *Phys. Review*, 1896-7, vol. IV, p. 297), which received the waves. The usual blackened vanes in this radiometer were replaced by mica strips, on which were deposited bright metallic platinum. By shielding the vanes on one side their rotation was obtained, as the action of the electric waves produced oscillating currents in the metal, and these currents perceptibly heated it owing to its ohmic resistance, and thus gave rise to the well-known radiometer action. The short electric waves were generated by means of a HERTZIAN doublet, with minute tungsten cylinders substituted for platinum. The wave-length measurements involved the use of a new form of reflecting echelon analyser.

By means of the equipment briefly indicated here NICHOLS and TEAR were able to produce and measure *electric* waves down to 0.022 cm. in length, which is "shorter than the longest known heat waves emitted by matter at high temperatures."

In a check experiment on their new apparatus, these investigators exposed the electric-wave receiver to RUBENS and VON BAYER's *heat waves* of 0.032 cm. wave length, and obtained "results identical with those recorded by these earlier investigators."

The range represented by the shortest wave length, that of gamma rays (γ -rays) from radio-active matter, to that of the longest HERTZ waves is now

practically explored throughout. The ratio of the shortest wave length to the longest wave length is about 1 to 20 million billion.

The accompanying diagram (Fig. 3) shows the complete span of the spectrum divided into arbitrary geometric intervals, "such as the ascending powers of two used in laying-off a piano keyboard on which the wave lengths of two notes an octave apart are to each other as two to one."

The authors remark: "Matter under the action of heat is capable of giving off radiations in the so-called infra-red, visible, and ultra-violet spectra; gamma rays are the natural accompaniment of radioactive disintegration, and there are various electric phenomena in the atmosphere giving rise to pulse-like disturbances resembling fragments of very long electric waves. But X-rays and the old and new short electric waves we may still regard as artificial or purely products of laboratory manufacture."

NOTES

In Fig. 2 (given on page 84) and Fig. 3 it is assumed that *all* the rays are produced as in an ordinary spectrum, and therefore that the prism which sorts them out is an ideal one capable of accommodating all wave lengths. In practice different sorts of prisms would have to be used, and in extreme cases no prisms are found suitable, so that the "spectrum" is really built up from wave-length data. The lines of demarcation are to some extent arbitrary.

The method of exploring the ideal spectrum is not quite so simple as indicated in Chapter X, but it serves to illustrate broadly the general principle therein indicated. This will be made more evident from a study of the work of NICHOLS and TEAR cited above.

NAME INDEX

- ARONBERG, 11.
 ARRHENIUS, 65.
 ASTON, 1, 4, 6, 11, 13, 16, 37, 41, 44,
 99, 120, 147, 148, 149, 150, 152, 153.
 BAIN, 69.
 BAXTER, 1, 49, 99.
 BAYER, 165.
 BAYLEY, 155.
 BIRCKENBACH, 1, 152.
 BOHR, 35, 46, 47, 48, 49, 50, 51, 53, 54,
 64, 65, 66, 72, 76, 78, 80, 93, 115,
 119, 120, 124, 125, 126, 127, 137,
 138, 155.
 BRAUNER, 21, 99.
 BROEK, VAN DEN, 28.
 BROSE, 74, 83.
 BRÜSSLERA, 38.
 BROWN, 116.
 CLARKE, 31, 33, 35.
 COMPTON, 134.
 COSTER, 23.
 CROOK, 31, 32.
 CROOKES, 5, 41, 42.
 DEBIERNE, 99.
 DEMPSTER, 4, 148.
 EDDINGTON, 38, 39, 71, 74, 90, 116,
 159, 160.
 EINSTEIN, 38, 70, 71, 73, 74, 76, 79, 80,
 117, 118, 128, 129, 133.
 ERNSHAW, 161.
 FISCHER, 135.
 FOURIER, 52.
 FOWLER, 53.
 HAHN, 103.
 HATFIELD, 83.
 HERTZ, 61, 86, 92, 163, 165.
 HEVESY, 23.
 HÜNIGSCHMID, 1, 152.
 JOLY, 40.
 KAYE, 83.
 KOSSEL, 64, 65, 66.
 KUSS, 1.
 LAMPA, 163.
 LANDENBURG, 66.
 LANGLEY, 163.
 LANGMUIR, 12, 15, 25, 30, 56, 58, 62,
 64, 65, 66, 75, 125, 126, 131, 145.
 LAUE, 68.
 LAVOISIER, 91, 92.
 LEBDEW, 163.
 LEDUC, 99.
 LEWIS, 15, 25, 56, 58, 62, 64, 65, 66,
 75, 125, 126, 131, 145.
 LUMMER, 82.
 MCALPINE, 153.
 MCLENNAN, 147.
 MARSDEN, 104.
 MASIUS, 87.
 MAXWELL, 61, 93, 163.
 METTNER, 104.
 MELLOR, 155.
 MENDELÉEFF, 22.
 MERTON, 11.
 MEYER, ROBERT, 87.
 MILLS, 151.
 MÖBIUS, 163.
 MOORE, 149.
 MORGAN, 153.
 MOSELEY, 9, 11, 28, 49, 59, 60.
 NEWTON, 71, 117, 118, 128.
 NICHOLS, 163, 164, 165, 166.
 ONNES, 77.
 OXLEY, 60.
 PASCHEN, 163.
 PERKINS, 104.
 PERRIN, 39.
 PLANCK, 47, 48, 52, 79, 82, 83, 85.
 POPE, 150.
 PRINGSHEIM, 82.
 RAMSAY, 10.
 RAYLEIGH, 82.
 REICHE, 83.

168 THE CHEMICAL ELEMENTS

RICHARDS, 99.	TEAR, 163, 165, 166.
RODWELL, 92.	THOMSEN, 155.
ROUGIER, 87.	THOMSON, G. P., 4, 152.
RUBENS, 163, 164, 165.	THOMSON, J. J., 4, 6, 135, 136, 147, 149, 159, 160, 161, 162.
RUTHERFORD, 17, 40, 56, 57, 59, 93, 119, 128, 140, 157, 159, 160.	URBAIN, 99.
RYDBERG, 15, 26, 27, 34, 132, 135, 154, 156.	VARDER, 104.
SAHA, 121, 122.	WASHINGTON, 31, 33, 35.
SCHRÖTER, 135.	WIEN, 82.
SCHUMANN, 147, 149.	WILLARD, 153.
SCOTT, I.	WOOD, 165.
SODDY, 4, 13, 99, 106.	
SOMMERFELD, 46, 54, 64, 74.	
STOCK, I.	

ERRATA AND ADDENDA

Page 2. Cu isotope "63" should read "63."

Page 26. 14th line from bottom, "LI" should read "Li."

Page 34. In Table, "Sc" next to Rb, should read "Sr."

Page 82. Equation, should read

$$K_{\nu} = \frac{h\nu^3}{c^2} \times \frac{1}{e^{\frac{h\nu}{kT}} - 1}$$

Page 107. In Table VIII, on left side, "AcB" should read "AcX."

Some newly-discovered isotopes have been added to Table I since the Subject Index and Appendix III were completed.

SUBJECT INDEX

Cross references are given in the text, but the Name Index may be useful
in this connexion

- ÆTHER, 70, 71, 118.
Alloys and crystal structure, 68, 69, 70.
Aluminium, single mass number of, 2, 152.
Antimony, isotopes of, 3, 153.
Atom as a cellular structure (?), 66, 109.
— — an electrical mechanism, 92, 93, 94.
— — — electrical system, 111 (*see above*).
— evolution, 39, 40, 41, 42, 43, 44, 45.
— of zero atomic number (?), 119, 154-162.
— structural irregularities of, 109, 110, 141.
Atomic binding processes. *See* Binding.
— disintegration by firing He nuclei into atoms, 138.
— "levels," 26, 27, 34, 35, 36, 50.
— number, definition of, 17, 18, 124.
— — and electron stability, etc., 108-112.
— — rule, Rydberg's, 15, 26, 34, 132.
— numbers basic factors in atomic architecture, 138.
— — tables of, 2-4, 34, 107.
— radiation illustrated by analogy models, 75-81, 82-86.
— weights, 2-4, 96-98.
BERYLLIUM, single mass value of, 2, 152.
Binding processes, 20, 23. *See* Chapters VI, VII, VIII.
Bohr atom, 46-55, 72, 78-81, 115, 121, 124, 125, 126, 127.
— — an analogy, 76-81.
— — and "octet" linkages, 137.
Bohr's theory and octet theory, 124, 125, 126, 127, 137.
Boron, isotopes of, 1, 2.
CADMIUM, isotopes of, 3, 151.
Carbon arc, 132-135.
— non-ionizable electrolytically, 139.
Cellular structure of atoms (?), 66, 109.
"Chance effect" in ionization, 120, 121, 122.
"Chemically," the word partly defined, 132.
Chlorides, metallic, mass spectra of, 148.
Chlorine, isotopes of, 2, 6, 43, 132, 148, 153.
— octet, 134.
Chromyl chloride, mass spectra of, 148.
Classical mechanics, 123, 127, 128.
Comets and electrons, 133.
Conducting and valency electrons, 142, 143.
Correspondence principle, 48, 50, 51, 52, 53, 54, 55.
Crystal structure of alloys, 68, 69, 70.
"DIFFERENTIAL" in atomic phenomena, 117, 118.
Disintegration. *See* Atom and Radioactivity.
Dynamo, 72, 73.
EINSTEIN'S theory of relativity, 38, 46, 71-74, 90, 91, 92, 123, 128, 129.
Electrical conductivity a part lattice movement of electrons, 142, 143.
Electrically neutral atom, 119, 122, 154-162.
Electron and proton in close combination, 116, 160.
— grouping in atoms, 64, 65, 66.
— repelled by nucleus if near enough to it (?), 160, 161.
— structure, 113-122.
Electrons, 56-60, 62.
— altering the number in the atom, 132-142.

170 THE CHEMICAL ELEMENTS

- Electrons and comets, 133.
 - protons, 16, 17.
 - one-fold structures, 113-122.
 - two-fold structures, 113-132.
- from nuclei as means of making elements, 139, 140.
- in atoms illustrated by magnets, 108.
- inner and outer, 140.
- Element evolution, 37-45.
 - of zero atomic number (?), 154-162.
- Elements in earth's crust, 31-36.
 - making them by displacing electrons and protons (?), 139, 140.
 - missing in periodic table, 25-45.
 - produced synthetically (?), 131-142.
 - specification of, 144-146.
 - symbols, etc., 1-4.
 - tables of, 2-4, 14, 24, 32, 34, 96-98, 107.
 - total number in periodic table, 21, 24, 33-36.
- Energy, aspects of, 87-94.
 - conservation of, 91, 92.
 - due to atom formation, 38, 39, 42-45.
 - forms of, 90, 92.
 - from standpoint of atomic physics, 87-94.
 - of radiation, 82-86.
 - philosophical views of, 87, 88.
 - relativistic view of, 90-92.
 - to ionize hydrogen, 140.
- GEOMETRIC considerations, Chapters VIII and IX.
 - Geometry of space a factor in atomic physics, 75-81.
- Gravitation a differential effect, 117-119, 122.
- Gravity, 70, 71, 73, 74, 117, 118, 119.
- HAFNIUM, 23, 24.
- Helium atom model, 126, 127.
 - nuclei (He^{++}) fired into atoms, 138.
 - $++$, 60, 120, 138, 147.
- H-nucleus made a neutral doublet, 116, 160.
- Hydrogen ions, 120.
- INERT elements not combinable, 135, 136, 149, 150.
 - gas heavier than Xe, search for, 149, 150.
- Inner and outer electrons, 140.
- Ionic theory and inertness, 65.
- Ionization and atomic stability, 119, 120, 138, 139.
 - cumulative, 121, 122.
 - potentials, 120, 121, 122.
- Ionization potentials and stability of atoms, 119, 120, 138, 139.
- Ions, hydrogen, due to loose binding of electron, 120.
- Iron, isotopes of, 2, 151.
- Isotopes, definition of, 4-16.
 - of tin, 3, 13, 43, 150, 151.
 - radio-, 96-112.
 - recent advances, 147-153.
 - table of, 2-4, 107.
- KOSSEL's views of the atom, 64, 65, 66.
- Kr₂ and Xe₂ (?), 149, 150 (*see* p. 136).
- Krypton isotopes, 2, 149.
- LEAD ethide and zinc methide for determining isotopes, 148.
- Lewis-Langmuir theory. *See* Octet theory.
- Light, velocity of, 88.
- "Limiting numbers," use of with atomic numbers (?), 109-112.
- Lines of force, 70, 78-81.
- MAGNETS, floating, 108.
- Magnitudes and relationships, 113-122.
- Mass numbers, 153 (*see* Table of isotopes).
 - spectra. *See* Isotopes.
- Matter, conservation of, 91, 92.
- Mechanics, classical, 123.
- Mercury method of eliminating, 151.
- Metallic vapours, method of eliminating, 151.
- Motor, 72, 73.
- NEUTRAL atom doublet, 119, 154-162.
- Neutralization of electricity, 57, 118, 119, 154-162.
 - problem, Chapter XIII and Appendix IV. *See* Energy.
- Nickel, isotopes of, 2, 147, 148.
- Nuclei as stabilizers of electrons in abnormal positions, 136-137.
- Numbers, a study in, 107-112.
- OCTET theory, 14, 15, 25, 56, 57, 58, 59, 62, 65, 66, 124-128, 131.
 - limitations of, 124, 128.
- Octets stabilizing electrons, 136, 137.
- Optical spectra of isotopes, 11.
- Overtones, 53.
- PERIODIC law, Chapters I, II, III, IV, VII, 124, 125. *See* Periodic relations.
 - relations, 14, 15, 20, 21, 22, 23, 24, 25-44, 106-112.
 - table, "pyramid type," 155, 156 (*see* p. 35).

SUBJECT INDEX

171

- "Periodic tables, 14, 15, 20, 21, 24, 34, 107.
 "Place principle" in atomic phenomena, 46-55.
 Planck's law of radiation, 82-86.
 Protons, freeness of in atoms, 39, 44, 45.
 — removing from nuclei to make new elements, 139, 140.
 — structure, 113-122.
 Protyle, 41, 42.
 QUANTUM radiation models, 75-81, 82-86.
 — theory, 46, 47, 48-55, 82-86, 123, 124, 125, 126, 127, 128.
 — — by analogy, 76-81, 82-86.
 — — limitations, 123, 126, 127, 128.
 RADIAL magnetic lines, 78-81.
 Radiation. *See* Spectrum and Quantum.
 — Planck's law of, 82-86.
 Radio-active constants, notes on, 99-106.
 — — table of, 96-98.
 Radio-activity, 95-112.
 — a deep-seated change, 18, 131, 138, 140, 141.
 — part cause of (?), 140, 141.
 Radio-atoms as electrical mechanisms, 95.
 Radio-isotopes, periodic table of, 107.
 Relativity, 38, 123, 128, 129, 133.
 Resonance potentials, 48.
 Rutherford's process of disintegration of atoms, 138.
 Rydberg atomic-number rule, 15, 26, 34, 132.
 SCANDIUM in the sun, 37, 44.
 Selenium, isotopes of, 2, 151, 152, 153.
 Sommerfeld's fine line theory, 46, 54, 74.
 Space lattices and interpenetrating forms, 68, 69.
 Spectrum, 83, 84.
 — bridging the gap of the, 163-166.
 Stability of radio-isotopes, 109-112.
 Sun's heat, cause of, 39, 40, 41, 44, 45.
 Synthetic production of elements, difficulties of the, 141, 142.
 TABLE of elements, 2-4. *See* Periodic table.
 — — isotopes (mass numbers), 2, 3, 4, 107.
 — — radio-active constants, 96-98.
 Tables, others, 14, 15, 20, 21, 24, 26, 27, 28, 32, 34, 92, 110, 120, 154.
 Tellurium, no isotopes yet, 152.
 Thallium, isotopes of (?), 107, 151.
 Theory, limitations in, 123-129.
 Tin and the whole-number rule, 150, 151.
 Titanium, isotopes of (?), 148.
 VALENCY and conducting electrons (?), 142, 143.
 — electrons in carbon and electric conductivity, 142, 143.
 — ordinary, and octet theory, 128.
 Velocity of light, 88.
 WAVES, electromagnetic (*see* Radiation), 84, 163-166.
 — short, produced electrically, 163-166.
 "Wedge" periodic table, 26, 30, 34, 35, 36, 107.
 Xe, and Kr₂ (?), 149, 150 (*see* p. 136).
 Xenon isotopes, 3, 149.
 X-ray analysis, 64, 67-70, 73.
 — spectra, 49, 50, 51, 55, 60, 64.
 ZINC methide for determining isotopes, 148

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